Scanning Probe Microscopy Image Processing Software User's Manual

FemtoScan

Version 2.2.90

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The Manual contains detailed description of "FemtoScan" software for scanning probe microscope (SPM) control and image processing. Control of SPM through local network or Internet using this software is described. In the beginning of this manual description of "FemtoScan" scanning probe microscope construction and principles of SPM image processing can be found.

Contents

Chapter 1

Introduction

1.1 SPM Installation

"FemtoScan" Software is intended to control Scanning Probe Microscope (SPM) and to process images acquired by SPM. The results of experiments depend much upon user's knowledge and understanding of scanning probe microscope operation principles, as well as data analysis and representation principles. Due to this, the beginning of this manual covers some information concerning SPM construction and its principles of operation, that can make your work more productive and successful.

1.1.1 SPM Set-up

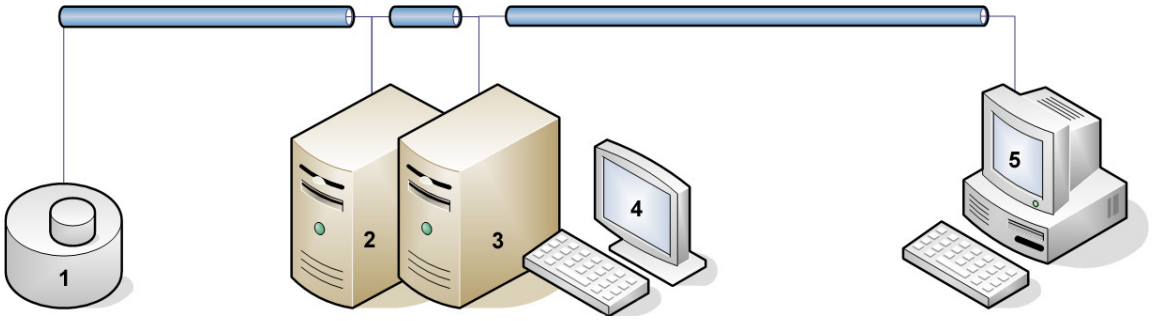


Figure 1.1. SPM Set-up. 1 - Microscope , 2 - DAC and ADC conversion unit, 3 - Stepper motor controller, 4 - DSP board, 5 - computers (left computer - server, right computer - remote user).

Scanning probe microscope set-up consists of several functional parts (units), that is shown on fig. 1.1. These parts are - microscope with piezomanipulator which drives the probe, tunneling current converter and stepper motor that allow to approach a sample to the probe; analog-to-digital (ADC) and digital-to-analog (DAC) conversion electronics, that also contain hi-voltage amplifiers; stepper motor control electronics; digital signal processing (DSP) board, that evaluate feedback signal; computer, that collect information and provide user interface. ADC and DAC electronics joined with stepper motor controller in one case. Board with signal processor (DSP - Digital Signal Processor) ADSP 2171 from Analog Devices Corp. installed in ISA slot of the computer.

1.1.2 Mechanical system of the Microscope

Figure 1.2. Mechanics of FemtoScan microscope.

General view of microscope's mechanics is shown on fig. 1.2.

Microscope mechanics consists from microscope base, which inside has piezomanipulator, sample landing system which consists of stepper motor with reduction gear, and two changeable measuring heads, one for operation in tunneling mode, and other for operation in atomic-force microscopy mode. The microscope allow to obtain stable atomic resolution on typical testing surfaces without any additional acoustic and seismic isolation.

1.1.3 Software structure

The server part of the software is working under Windows NT or XP operating systems. The client part can work under Windows 95 also. These operating systems were chosen as a platform for the software mainly because they are convenient, well-known, available for a user, and have a network interface.

Software structure can be divided into several levels (fig. 1.3). The lower level - DSP board signal processing program. Second level - operating system driver, that allow to exchange data with DSP board through input/output ports. Third level - Server, that allow remote users to connect to the microscope, and forth level - client software user work with. This structure is a result of qualities this system should satisfy: precise process synchronization, hi-speed data transfer, network support, convenience in usage. Synchronization is provided by DSP board, hi-speed data transfer is obtained by installing DSP board directly into motherboard slot, and by denying to use standard data transfer

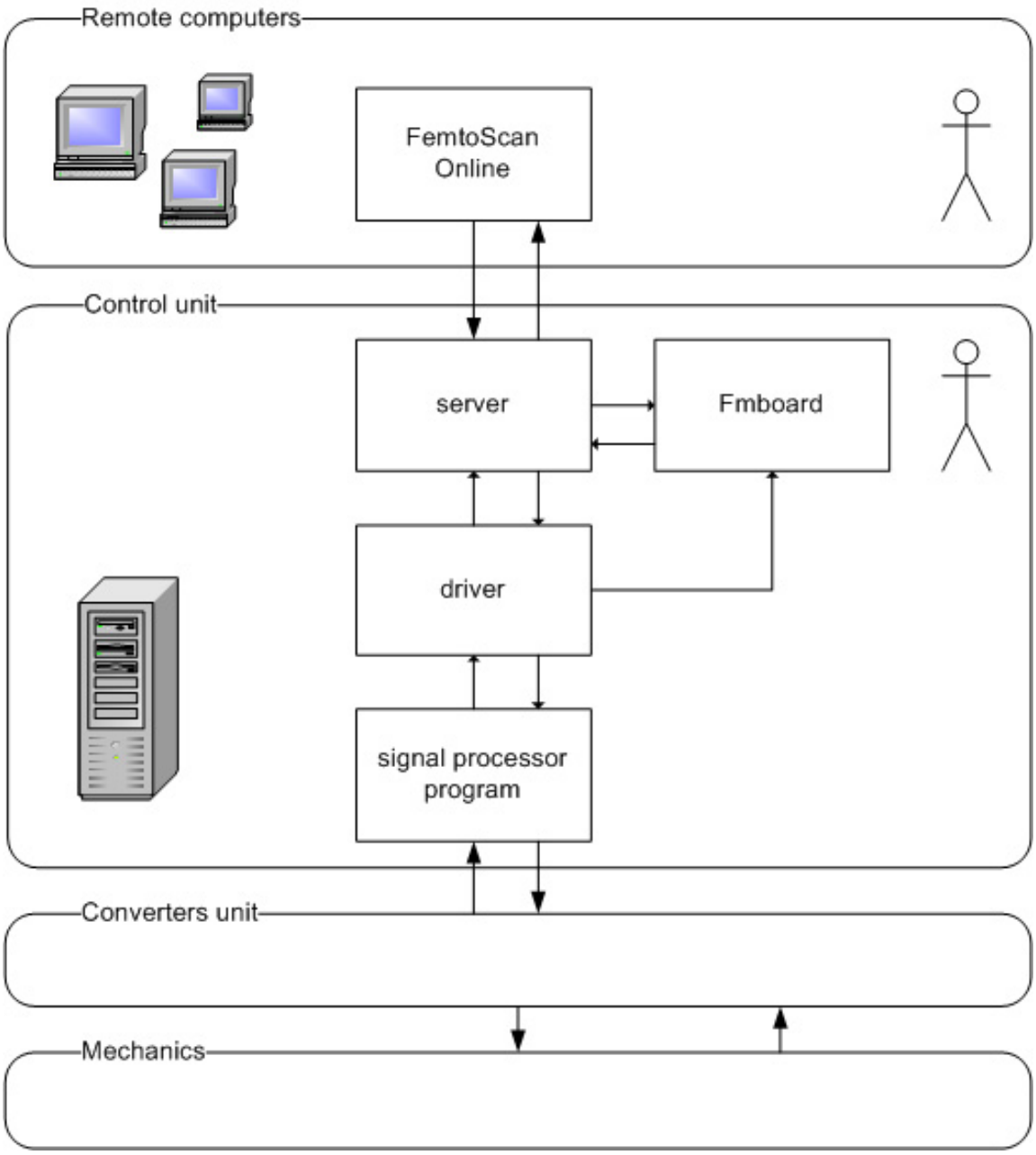


Figure 1.3. Software structure.

scheme which use slow data transfer devices (COM, Parallel or USB ports). Client-server program structure make possible to use networking.

These components will be described in details further.

1.1.4 DSP board program

DSP board program forms all driving signals for DAC-ADC electronics and stepper motor controller. These driving signals set DAC values, start signal conversion, define stepper motor mode of operation, start and stop the motor. Driving signals formation is defined by scanning regime and by feedback parameters. There is a timer in DSP processor, that is allow to make presize synchronization of scanning process.

Measured signal value (it can be tunneling current, interaction force or other...) goes through ADC to signal processor, which evaluate feedback signal. For feedback signal evaluation standard scheme with integral and proportional gains is used. Afterwards values of measured signal and feedback signal go to a computer for further analysis.

The fact that feedback loop is closed on signal processor and computer doesn't participate in feedback signal evaluation allow to make feedback more stable and independent from computer work. What is important, it allow to control the microscope under systems like Windows 95 or NT. So, computer is processing data, and DSP board runs the tasks, in which time is critical.

Evaluated feedback signal goes to piezomanipulator's Z-axis. Beside this, program generate signals that move the probe in X- and Y- coordinates. Simultaneously with this movement image data can be obtained and stored in the buffer for further transmission to the computer (this is a scanning mode of operation), or movement can be done without data transfer (this is a positioning mode of operation). In the standard mode up to 2 ADC signals can be measured at the same time, and maximum amount of signals from ADC that can be measured simultaneously is 16. Also, by controlling stepper motor movements the program control movement of table with a sample. This regime is used to land or to retract a probe to the sample.

All feedback and movement parameters and ADC addresses can be set by changing variables that stored in signal processor memory, and it doesn't need to rebuild the program to do this. Thus scanning parameters can be tuned by changing these variables, so the microscope can be fully controlled by computer. This allow to automate scanning process. And by using network technologies fully supported by "FemtoScan" software, it is possible to drive the scanning process even from the other side of the Earth.

1.1.5 Operating system driver

All communication between a computer and DSP board are going trough input-output ports of ISA bus. Access to these ports in Windows NT operating systems family is allowed only for drivers, that work on the operating system's core level. So, the driver is needed to escape this limitation. Besides, data buffer in the DSP board become full with rather high speed during scanning, and these data need to be taken with some period. In other case information will be lost. Programs that run on the user level of operating system depend much upon the systems resources, number of programs running, and due to this they cannot provide speed and synchronization level that is needed to communicate with input/output ports.

When the data stored it the DSP board are ready to transfer, it generate an interruption. Responding to this interruption driver reads data from the board and transfer it to a server for further processing. Different interruption processing scenarios are possible depending on scanning regime. Obtained data are filtered in special way to exclude unnecessary information. It allows to reduce processor usage.

1.1.6 Server

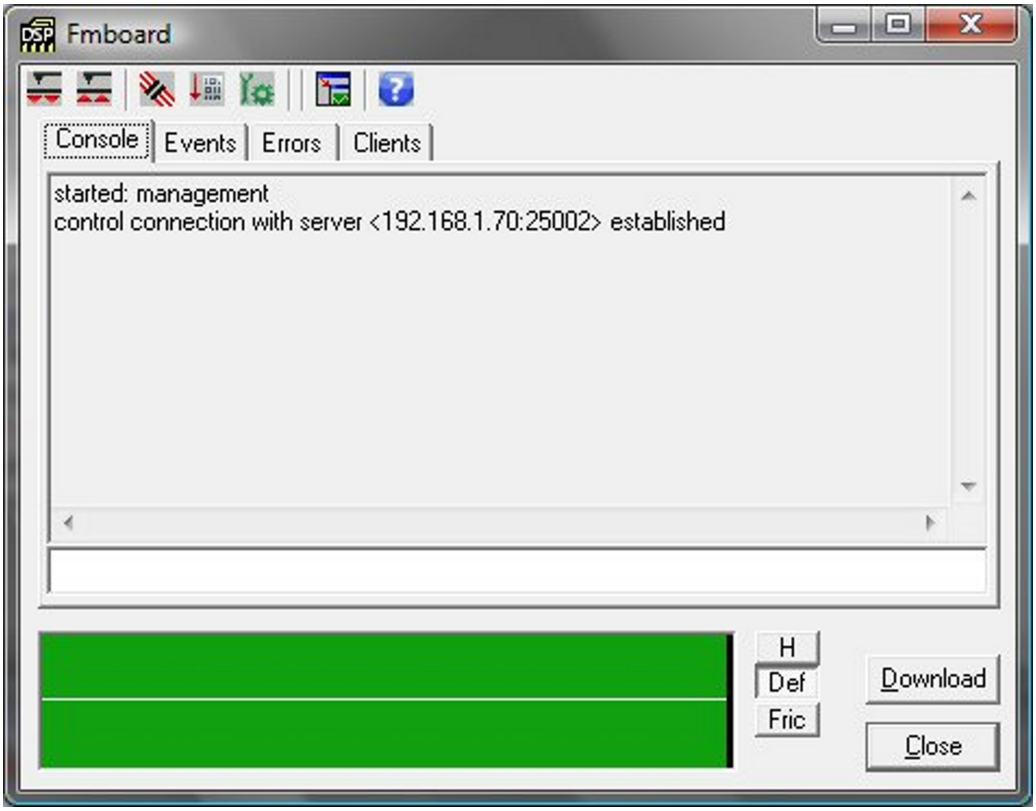


Figure 1.4. Server's working window. This interface allows to control microscope work and gather different statistical information on users work.

Server part of the software creates connections between operating system driver and client(s), i.e. microscope users. This program is installed on the computer with DSP board only, and it differs this program from client software part, which can be installed on every remote computer. Server provides data acquiring from DSP board, data storing and data transfer to remote clients. The server provides interface for scanning process monitoring, allow to control sample table movement and to download program to DSP board. Working window of the Server software is shown on fig. 1.4. Server has an oscilloscope window that can show driving signal or a feedback signal.

Parameters that can be defined using the server software are — probe landing velocity, ADC addressing, maximum allowed number of users and others. An independent data buffer is generated for each client. Information from this data buffer is loaded in asynchronous regime. Information about current connections can be shown in event window with special command.

Only one user can control the microscope. To do it user should connect as Master. The rest of the users can observe scanning process only (in this case users connect as Client).

If a connection between user and server was broken, user disconnected from the server automatically. This allow to escape internal data buffer overflow. When a user disconnecting from the server it doesn't affect other users work because data transfer is going in asynchronous regime.

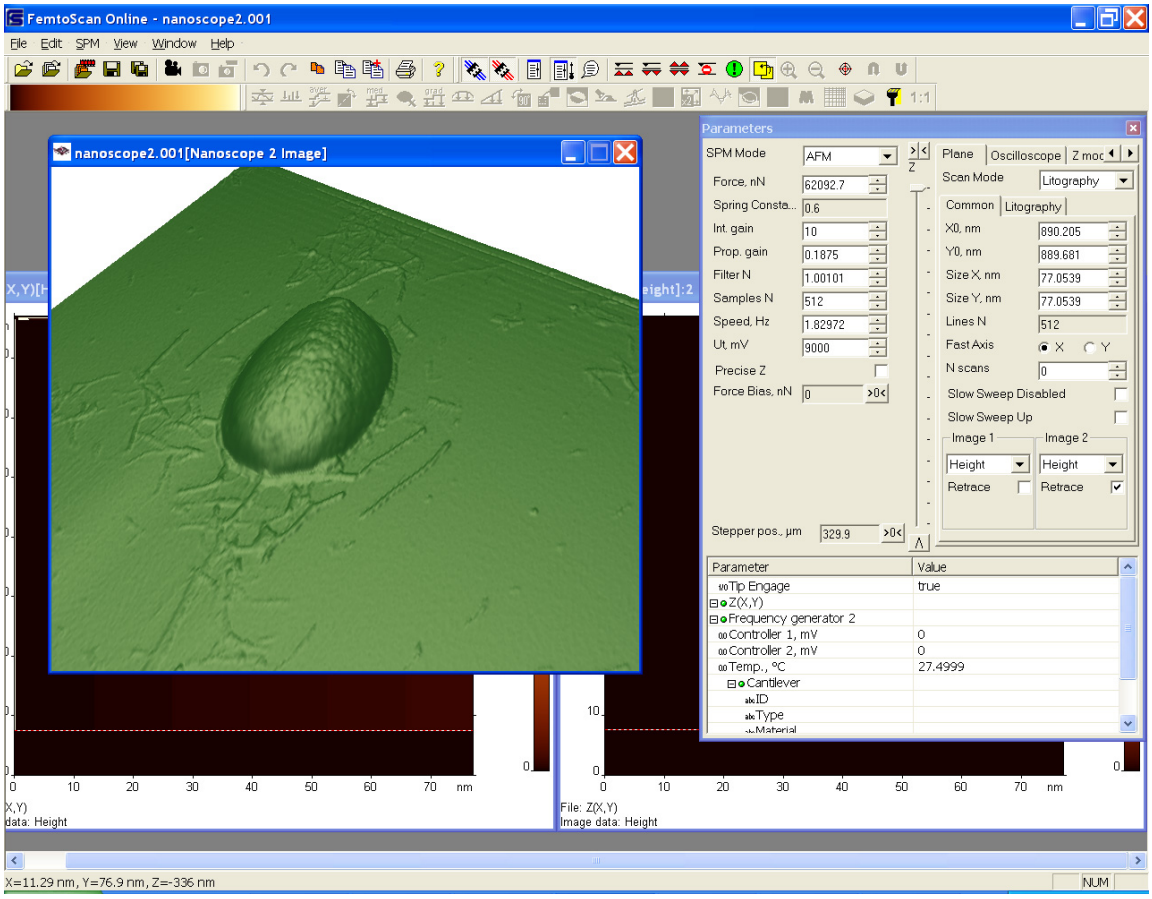


Figure 1.5. Client software part user interface.

data processing functions	data analysis functions	service functions
Vertical scaling	Section	File saving
Averaging by lines	Distance measurement	File deleting
Averaging by matrix	Isoline determination	File quick viewing
Reflection	Angle measurement	File text header viewing
Median filtering	Object length measurement	Macro command creating
Morphological filters	Reconstruction of 3D Images	Color palette modifying
Differential filters	Features searching	Referencing palette to selected region
Image addition and subtraction	Roughness measurement	Commands Undo/Redo
Changing image Resolution	Fourier-analysis	Image duplication
Threshold filtering	Correlation analysis	Saving images to a clipboard
Subtraction of surfaces (of 1-st and 2-sd order)	Histogram calculation	Saving images in BMP format
Rotation	Highlighting (gradient transformation)	Exporting images to different formats
Linear spline		

Table 1.1. Functions that are realized in client software part

1.1.7 Client

Client software part is a program, with which user work. Because of this a special attention had been paid to developing this program and making it better.

This program can run under Windows 95, Windows NT and Window XP operating systems. TCP/IP protocol is used to connect to the server. This allow to connect to the server not only within local network, but also through Internet.

All scanning parameters, that were defined by user, are transferred to the server and then to a microscope and to other users, connected as clients. After the scanning process is started number of windows are open. In this windows different data are representing in real-time manner — obtained images, their sizes, scanning mode, feedback parameters, current probe coordinates, scanning speed. At the same time user can process the data acquired using wide range of different functions, included in the program. Picture 1.5 representing client program main window during scanning process. Panels that shows current configuration and window with obtaining image can be seen.

Client-program has lots of different functions for SPM image processing and analysis. With this functions user can easly extract needed information from obtained data. These functions are listed in 1.1 table. If some sets of operations are used frequently it is possible to group these operations in single macro command, which can significantly decrease time loses.

The program saves images in format compatible with Nanoscope-III file format, which is used on microscopes from Digital Instruments^{TM}. This allow to process obtained images with this rather wiedly spread SPM systems also. This concerned not only to surface images, but to one dimensional data ($I_{tun}(Z), F(Z)$ and others) also.

1.2 Image formation and processing methods

Main results of different objects studying using scanning probe microscopy methods are 3-dimensional images of these objects usually. And how well they will be interpreted depends on skillfulness of a researcher. Taking this into account, is important to mention, that still there are

some traditional approaches to image formation worth knowing during image analysis.

Scanning probe microscope appeared at the moment when computers were developing intensively. Digital methods of information storage, that was developed for computers, was used in this kind of microscopes to store 3-dimensional images. It gives significantly more convenient image processing, but photographic quality, common for electronic microscopy methods was lost.

Information obtained with scanning probe microscope is represented in a computer as numbers in 2 dimensional matrix. Each number in this matrix, depending on scanning mode, can be tunneling current value, or cantilever deflection value, or a value of a more complex function. If you show this matrix to someone, he hardly can get any meaningful information about the studied surface. So, the first problem arises — how to transform the numbers to more convenient form. It can be done by following routine.

Numbers in the matrix are in some range, there are maximum and minimum values. This numeric range is possible to put in accordance with some color palette. Thus, every matrix value is represented by point of some colour on a rectangular image. Column and row, that contain this value, becomes point coordinates. As a result we have a picture, on which surface height represented by colour, just like on a map. Usually maps has dozens of colours but our picture has thousands of colours. Points with small height difference usually represented by similar colours for convenience.

It can happen (and usually it happens) that initial data range is wider than number of accessible colours. In this case some data can be lost, and this problem cannot be solved by increasing number of colours due to limitations of human's eye abilities. So, additional data processing is needed, and this processing should be different depending on tasks to be solved. Somebody needs see the whole picture, the other needs to see some details. Different methods are used to achieve this variety in data representation, and the rest of the chapter will describe this methods. Images on which point height represents by a colour will be considered as an example.

1.2.1 Average slope subtraction

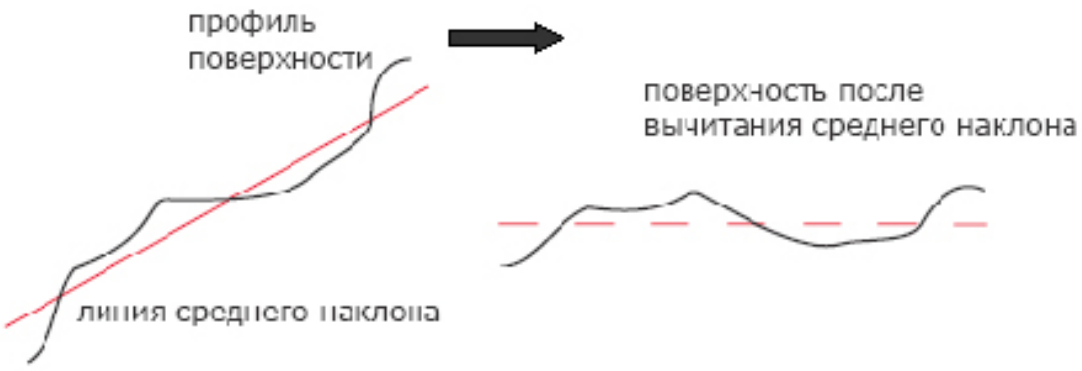


Figure 1.6. Avreage slope subtraction.

Surface images obtained usually has some slope, which can appear due to different causes. It can be real surface slope; can be temerature drift, that causes sample to move during scanning; it can be due to piezoceramic manipulator non-linearity. However, these reasons lead to general surface slope, and it prvent object structure to be exposed. To avoid it average slope plane is subtracted from the initial matrix. Let's explain it on one-dimensional example (see fig. 1.6).

Matrix with narrow data range is obtained as a result, and small details are represented with

greater number of colours and become more visible. Piezomanipulator non-linearity can cause the surface image to be concave. In this case more complex surface - parabolic or hyperbolic - needed to be subtracted from the surface image.

1.2.2 Averaging data

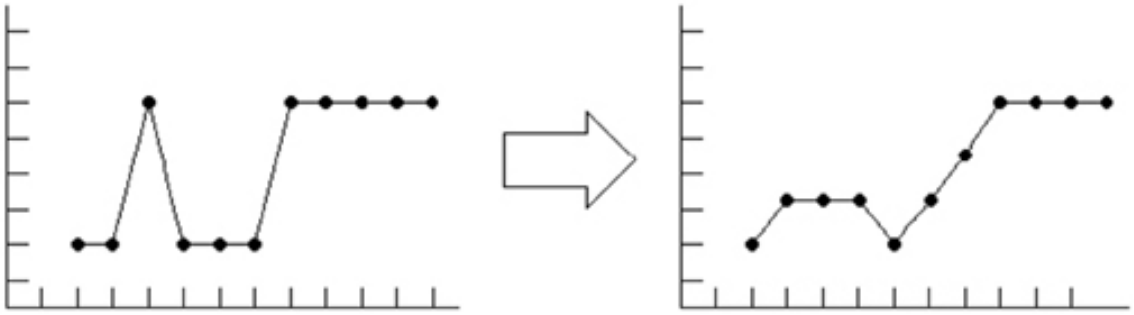


Figure 1.7. Averaging data

There is some noise component in every surface image. To reduce or remove this noise component height in every point can be changed to average height value of its closest neighborhood (see fig. 1.7). If it doesnt work - noise level is too high - more complex method should be applied. You can, for instance, remove high-frequency part from the initial signal. In fact, the averaging we described before is a kind of high-frequency noise filtering. The next thing you can do is to increase averaging region's size. Let's look at one-dimensional (a sting, not a matrix) example of such averaging operation.

Let's draw a plot, on which X-axis corresponds to coordinate of a point, and Y-axis - to point value. As a result we have string profile. This profile before and after filtration is represented on fig. 1.7.

1.2.3 Median filtering

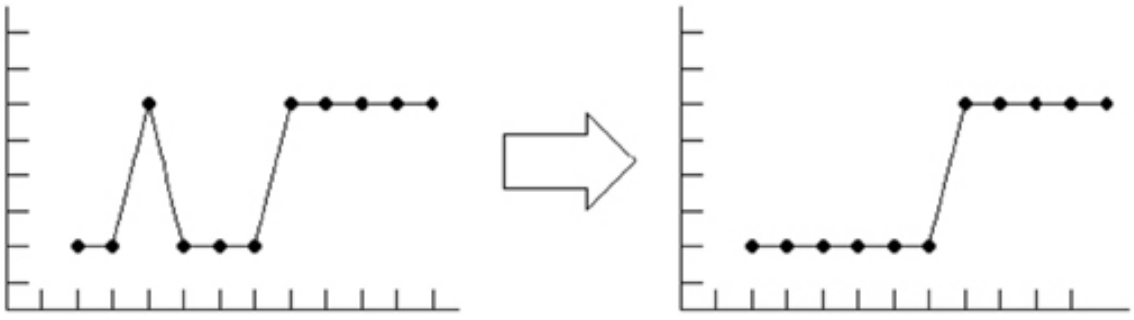


Figure 1.8. Median filtering

Good results can be obtained using median filtering. This non-liner image processing method allow to remove sharp peaks, but leave steps untouched. The last differ this method from averaging. Let's explain this filtering method using one-dimensional example. If we put point's coordinate on

horizontal line, and point's value on vertical line, we obtain two-dimensional profile. For filtering point we get values of its neighbors and put them into table. Then we sort this table by growth, and take value in middle table cell as a new value of the point.

Thus if we had a sharp peak in a point, the point's value hit the last cells in the table and does not go to the final image. But steps go through this routine without any change (see fig. 1.8). It is very easy to notice a difference between results of median filtration and averaging (see fig. 1.7, 1.8).

1.2.4 Scan lines averaging

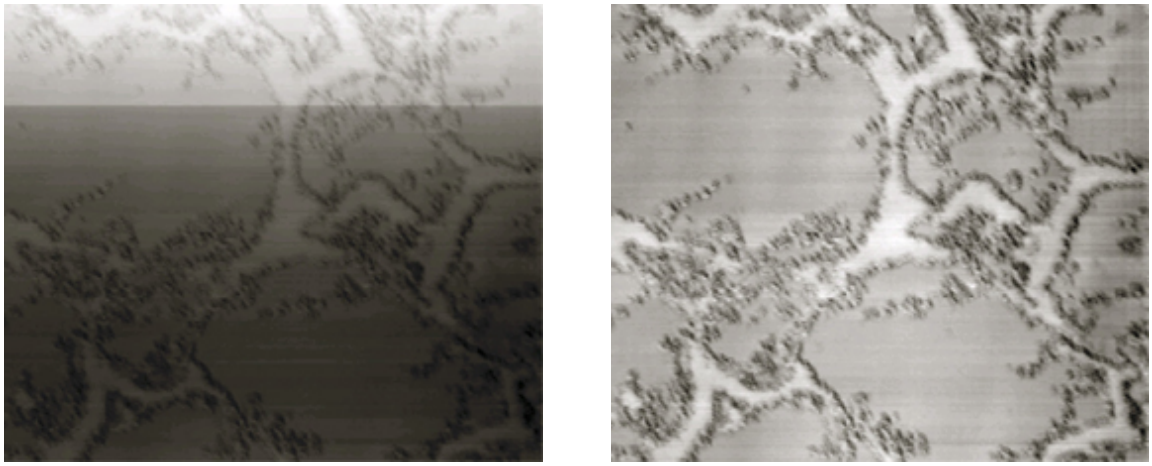


Figure 1.9. Multicomponent organic film surface image. Left picture - before averaging, right picture - after averaging.

Characteristic feature of scanning probe microscopy images is that they formed line by line. Thus an image has special features due to direction of scanning line formation. The thing is that if time of single scan line obtaining is small, then time between acquiring of neighbor strings are significantly larger. If, during the last process, something that can influence the scanning process happens (like loud noise for instance), neighbor scan lines could be significantly displaced in up- or downwards direction. Due to this a horizontal step not existing on the real surface will appear on the surface image. To remove this defect scan lines averaging is used. All the scan lines are put upper or lower so that in the new image the average height along each scan line is the same. This operation change a row profile of the image - by removing all the steps, and it doesn't affect the column profile of the image (see fig. 1.9).

1.2.5 Surface highlighting

Human's eye differs hi-contrast objects better. That is why small objects are unnoticeable in compare with big ones on the images in which object height is represented by colours. What we can do in this case?

There is a way to combine information about objects height with the information about height of small detail on its surface. Just imagine that you are flying over the the Caucasus mountains. You see all the ravines and canyons, though height overfall they has is significantly smaller than mountains itself. This is due to game of light and shade. If the sun is in zenith, than horizontal parts of the surface will be brighter than the slopes. Our mind is calculating objects height by itself.

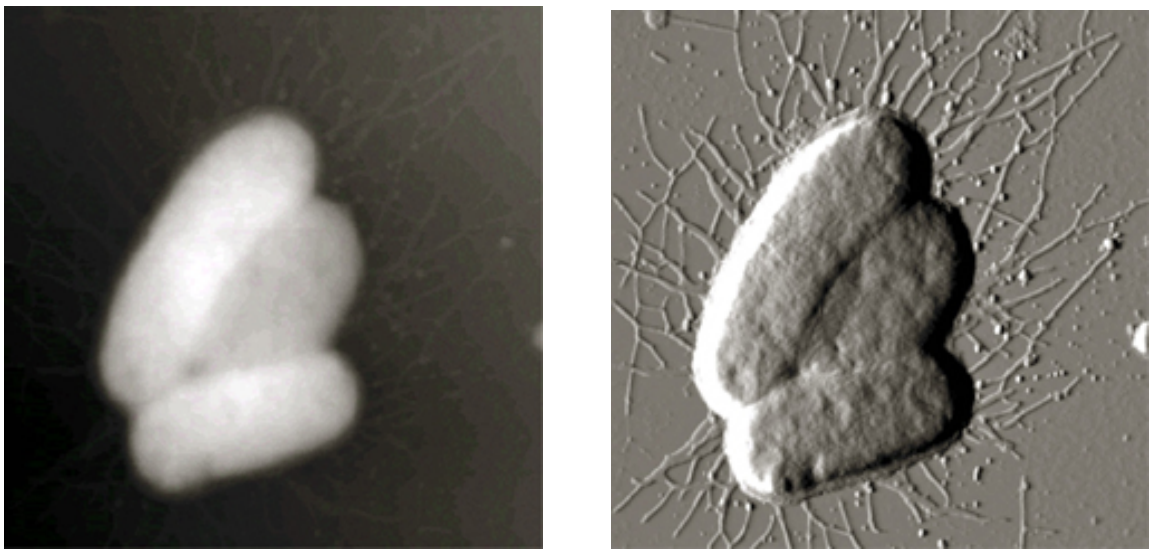


Figure 1.10. Computer processing allow to increase an image contrast. On the left picture initial image is shown, on the right — the image that was highlighted. Studying object - bacteria Escherichia Coli. Image size 4,6 × 4,6 mkm^2.

Thus, applying this highlight effect to surface image will reveal small details without losing information about the big ones (see fig. 1.10).

Chapter 2

SPM Control

2.1 Server

The server part of the software package runs on the computer with DSP board. The name of the Server program is fmboard.exe. When minimised, the program window dissapears from the Tasks List and stays only as an icon in the systems tray region (usually in the bottom right . Double clicking the icon causes the program window to appear, right-clicking the icon calls command menu. Commands from this menu can be executed without opening program window.

2.1.1 Server's main window

The main instrument panel, message window, scan windows, client list window, the DSP download button, the oscilloscope emulation, the DSP download button and the program exit button (fig. 2.1) are all located in the servers main window instrument panel.

Instrument panel

The instrument panel contains (from left to right): sample fast approach/retract buttons, stepper power supply on/off button (if this feature is enabled in program configuration), show statistics button, sound on/off button, volume control buttons, toggle to small window button (in the small window regime only instrument panel and oscilloscope emulation are shown, window title is reduced, window is always on top of other windows), and the button that opens the About window.

When a user mounts a sample for the first time, it is possible to run fast sample approach to close the distance between the sample and the cantelever quickly. However, during this procedure, it is important to control the distance between the probe and the sample visually or by using an optical microscope.

The sound on/off button allows the user to output the signal from the oscilloscope to a sound device installed on the computer. When this function is enabled, other programs cannot use the sound device and cannot output sound. If another program is already using the sound output device, the sound button on the FemtoScan programm will not be operational.

Message window

In the Events message window, the information on the current microscope status is displayed. All messages are stored in a file with the following filename format: fmbDDMMYY.log (DDMMYY – current date, month and year) in the directory where the fmboard.exe file is stored. The Errors

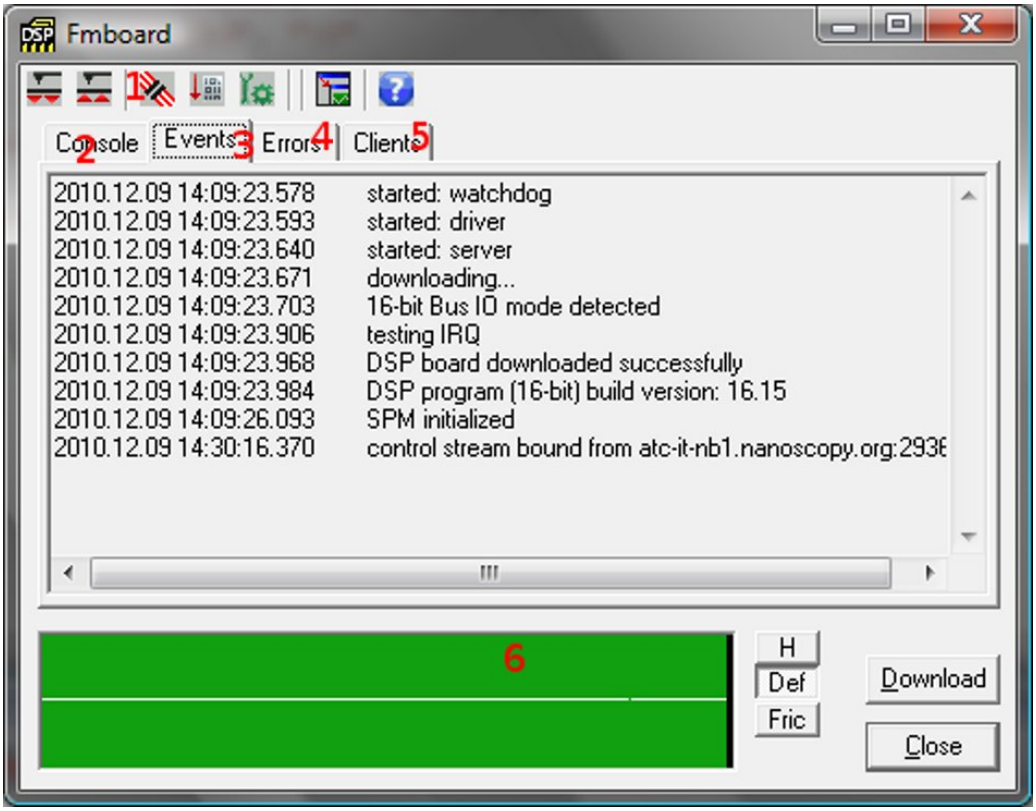


Figure 2.1. Server's main window. 1 - Instrument panel, 2 - message window , 3 - scan process window, 4 - client list, 5 - oscilloscope.

window shows errors information (such as those associated with sudden user disconnection, network problems, etc.). The Log file for this window is named fmberr.log, and is stored in the same directory. Every error message is accompanied by a sound signal.

Scan windows

The scan windows show the results of the surface scanning process. In regions colored blue, the probe does not reach the sample surface; in the regions colored red, the probe crushes the surface. In this instance, an immediate probe retraction from the sample is necessary in order to save the probe and the sample from serious damage.

Client list

Clients list shows the names of connected users and the amount of buffers filling. Users, connected in Client mode, are shown with the  image; connected in Master mode — with the  image. User can choose one or several clients and send them a message or disconnect them by right-clicking on the selected items. In case of client's buffer overflow, the client is disconnected automatically.

Oscilloscope

In the oscilloscope window, the feedback signal, deflection signal (ADC#0) or friction signal (ADC#2) can be shown. The user can switch between these signals by using the buttons on the right of the Oscilloscope window. The signal showed by oscilloscope, is automatically scaled in following way - 0 should be in the center of the window, all signal fits the window, positive values represented in upper window part. On the right of the window is a 15-segment logarithmic scale indicator, every segment of which corresponds to a 1 signal bit.

DSP board initialzation

By using the Download button it's possible to initialize the DSP board and download a DSP program into it. It is necessary to do this every time one turns on the microscope, for the DAC initial values are set and the ADC is caliberated during the download. It is not recommended to download the program into DSP board during the scanning process. After downloading all current parameters configured by the user (piezomanipulator position, tunneling current setting, feedback gains, etc.) will be restored.

2.1.2 Server configuration

The server configuration window can be opened by right-clicking the program icon in system tray and choosing the Options command or by choosing this command from a menu that appears if the user were to click an icon in the top left-hand corner of the program window. In the configuration window user can set values that define correct server behaviour and data interpretation. Note that only advanced users should change these values. There are 3 buttons at bottom of the window - Ok, Cancel and Apply. If the Apply button is pressed, the program will change configuration without closing this window.

General calibration

Calibration data is transferred to each client at connection. This allows the user to set the correct scanning parameters. The calibration tab shows calibration data that were obtained by measuring test samples. User can change following values:

- Max DAC, V - maximum DAC output voltage.

X,Y,Z Gain - amplifying coefficient of high-voltage amplifiers.

X,Y,Z Sensitivity, nm/V - piezomanipulator sensivity at corresponding axis. If sensivity is set, for example, as $X_{Sensitivity} = X_{sens0}$ and graphite lattice period obtained in calibration measurements is equal to L_0, and from tabulated data it is L_1 then correct sensitivity value can be found using the following equation:

$$X_{sens1} = \frac{X_{sens0}}{L_0} L_1.$$

- Inverse Z - user must switch on this flag if the piezomanipulator has a reverse polarization. To get a correct value, please consult the supplier.
- Hysteresis - Path to hysteresis calibration file (see 2.1.2).
- Temperature - Path to temperature controlled sample table calibration file. File format described here - B.
- Variables - Path to variables initialization file. At the present moment this feature is in the development stage.

Hysteresis calibration

To correct non-linear distortions in sizes of the sample and objects on it, that arise due to piezoceramics hysteresis, a calibration file is used. This calibration file is generated by "FemtoScan" program using the data entered by user (see 3.7.3).

If you have a calibration file, you can use it by selecting Calibration tab and enter a path to it in a field that appear.

STM Calibration

STM Cal. tab allows the user to adjust calibration data for the tunneling mode of SPM operation.

- Max It, nA - maximum tunneling current. This value depends upon the sample table that is used (with hi or low sensitivity). This value can be calculated from the following equation: $I_t = U_t/R_t$,where R_t is sample table resistance.
- Max Ut, V - Maximum potential difference at the tunneling gap.
- Inverse feedback - sign of feedback. With positive feedback incriase in error signal leads to an increase in feedback signal, with negative feedback increase in error signal leads to a decrease in feedback signal. In STM mode, positive feedback is used.
- Inverse It - Error sign signal. Installed in the STM head is an inverting operational amplifier. Consequently, the error signal comes to ADC in an inverted form.
- Feedback channel - channel of the 1-st ADC. From this channel, the feedback signal is taken. At the present moment 0 channel is used for error (deflection) signal, and 1-st channel used for RMS signal (which is used as feedback signal in Resonance AFM mode).

AFM calibration

AFM Cal. tab allows the user to adjust calibration data for atomic-force microscope mode of SPM operation.

- Max Deflection, nm - the maximum value of cantilever deflection.
- Spring Constant, N/m - the cantilever spring constant.
- Inverse feedback - see. 2.1.2. In the AFM mode of operation, feedback is positive.
- Inverse deflection - sign of an error (cantilever deflection) signal. In the AFM mode error signal is not inverted.
- Feedback channel - see. 2.1.2.

Resonance AFM calibration

Resonance AFM Cal. tab allows the user to adjust calibration data for resonance atomic-force microscope mode of SPM operation.

- Max Deflection, m - maximum value of cantilever deflection amplitude.
- Max Zmod Amplitude, mV - maximum voltage for amplitude modulation of cantilever oscillations.
- Max Zmod Frequency, Hz - calibrated maximum frequency for amplitude modulation of the cantilever oscillations.
- Inverse feedback - see 2.1.2. In Resonance AFM (RAFM) mode, the feedback is negaive.
- Inverse deflection - error signal sign. For the Resonance AFM head, the error signal is not inverted.
- Feedback channel - see 2.1.2. In RAFM mode, channel 1 is used due to the fact that the error signal is modulated with the cantilever oscillation frequency.

COM-port calibration

Aux cal. tab allow user to adjust calibration data and parameters for an additional data channel for the data that came trough COM port.

- Auxiliary port enabled - Flag that turns additional data channel on. If this flag is set, one additional data channel - Auxiliary - appears within the image scan parameters of the client-program.
- Max AUX port data - Maximum value for the data that is being received.
- AUX port data units - units of measurement for receiving data.
- COM port number - number of the COM-port.
- Configure... - button that calls the configure dialog for the chosen COM-port.
- Initialization file path - Path to an initialization file.
- Edit... - this button calls the initialization file editor. The file format is described here: C.

Network configuration

The Network tab allows the user to configure the following properties:

- Listen IP - IP-address of the server that awaits client connection. The user can choose one or all available addresses.
- Listen port - TCP/IP port, which is used for remote clients connection.
- Max. Users - Maximum allowed number of connected users.
- Buffer Size, Kb - When any client's buffer reachs this size, th client receives a smaller amount of data (client doesn't recive image data)
- Max. Buffer Size - maximum allowed buffer size. When client's buffer size exceeds this value, the server disconnects that client automatically.
- Max. idle timeout, min - if client that was connected as a Master is idle more than this time, the server disconnects that Master-client automatically.

HTTP server configuration

- Enable WWW server - enables WWW server. With a WWW server enabled, the current images would be accessible via the Internet. Images become accessible after SPM-client has first connection in a Master mode and the scanning process has started.
- Listen IP - The IP-address at which the server is awaiting for client connection. One or all available addresses can be chosen.
- Listen port - port which is used for web browsers connection. Usually all browsers connect to 80 port.
- Max. users - Maximum number of users connected at the same time.
- Refresh timeout, s - the image will be refreshed in this time interval.

DAC numbers

A tab labeled DACs allows the configuration of the DACs addresses that are responsible for piezomanipulator movement coordinates, tunneling gap voltage, stepper motor control, modulation frequency in RAFM mode and sample temperature control.

High resolution DACs numbers

On a tab labeled Subst. DACs addresses of DACs that responsible for high resolution data obtaining from X, Y, Z coordinates of piezomanipulator can be configured. Values in the field Gain show their amplification coefficients (compare to 2.1.2). These values are in agreement with parameters of high-voltage amplifiers, and the user can change these values only when these parameters are changed. This operation should be preformed only after consulting the supplier.

Sample landing preferences

Among the numbers from the Values tab, the user can change the following:

- Landing It - tunneling current value (in % from that was set as a bearing value for scanning) that, if reached, stops the tip from landing the sample.
- Landing delay - number of delay cycles corresponding to singe motor step during ordinary (started by the client) landing process. Usually 5000 cycles correspond to one second. The shorter the landing delay, the faster a sample moves. However, too short of a landing delay may cause instability in stepper motor work.
- Landing length - maximum number of stepper motor steps. If reached, the landing process is halted and the user is asked whether landing should be continued.
- Landing step - precision of sample positioning, observed by the client.
- Draw back on every step - landing mode which checks whether the surface can be reached. During the landing process piezomanipulator fully retracts the sample before every step. After the step piezomanipulator returns to the initial position. If during the last operation feedback becomes active then landing is considered done.
- Draw delay - delay (in DSP cycles) between steps during landing/retracting by piezomanipulator. Value 0 corresponds to absence of this delay.
- Draw stepping - value of the piezomanipulator step during landing/retracting by piezomanipulator.

Stepper motor configuration

- Forward value - a value that sets forward direction of stepper motor movement.
- Backward value - a value that sets backward direction of stepper motor movement.
- Toggle bits - bits that switched during stepper motor movement.
- Fast move delay - number of delay cycles during sample landing/retracting.
- Step size, nm - size of one motor step.
- Enable "Power On/Off" - this field allows the user to control the stepper motor's power supply. After enabling this feature, an additional button responsible for turning stepper power supply on or off appears on the instrument panel. If the user activates the stepper motor movement, the power supply will turn on automatically.
- "On"/"Off" value - values that set corresponding power supply status of the stepper motor.

Additional data acquiring channels

By using the Channels tab, the user can configure bits of the stepper motor DAC that are used to switch commutators which pass signals to ADC.

DSP Timing

On the DSP Timing tab DSP and microscope's electronic main working frequencies can be configured. It is strongly recommended not to change these values.

Events logging

The Logging tab configures logging options for events and errors. It is possible to turn off logging, change save path for log files, and log file names. It is also possible to put special symbols inside the names, that will be changed to current month, year and day:

%a short name of a day

%A full name of a day

%b short name of a month

%B full name of a month

%d day of a month (01 - 31)

%j day of a year (001 - 366)

%m month (01 - 12)

%U number of a week in a year, with Sunday as a first day in a week (00 - 53).

%w day of a wek (0 - 6; Sunday corresponds to 0)

%W number of a week in a year, with Monday as a first day in a week (00 - 53).

%y year without specifying a century (00 - 99)

%Y year with century specified

%% percent symbol

Driver configuration

On the Driver tab DSP interrupt and I/O ports addresses can be configured. User can change these values if he has administrator privileges. Otherwise, these fields wouldn't be accessible for editing. The parameters configured should correspond to the values set on the DSP board by jumpers.

2.2 Client

In the client part of the "FemtoScan" software package ("FemtoScan" program, file femtoscan.exe) all scanning parameters can be configured. All commands that control scan process, sample landing/retracting come from the client program. In principle, the scanning process does not need an interactive communication with the server. This, however, allows one to operate the microscope from a remote computer through a network. SPM menu commands and buttons on a SPM instrument panel are meant to control the microscope. SPM menu can be found at any moment of program work, and SPM instrument panel can be switched on or off — a tick near a Toolbar SPM menu item is responsible for this.

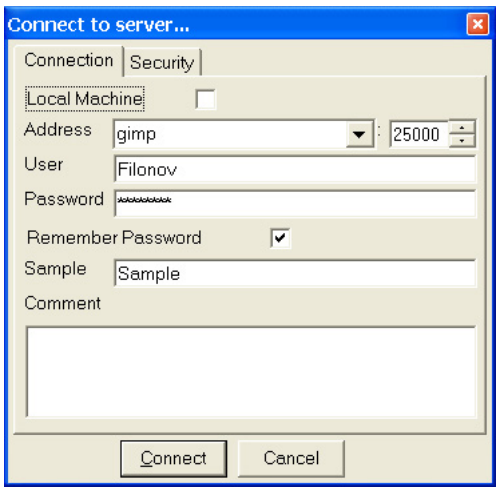


Figure 2.2. Connecting to a server in client mode. Connection window.

2.2.1 Connection to a Server

To connect to a server, select the Connect as Master (button) or Connect as Client (button) command in the SPM menu. It is possible to connect as Master if there are no other masters connected to the microscope.

When a connection is started, a window showed on fig. 2.2 appears. In this window one should enter the connection address as welle as some additional data. When the server is on the same computer as the client program, it's enough to put a mark in 'Use local machine' check box. Then one can fill in the remaining 3 fields. If the server is at a different location, it is that adress that should be noted in the Address field. In the Microsoft Windows Network local network, a name (like COMP145), its URL (like mycomp.mydomain.ru),or an IP address (like 123.231.111.10) can all act as adresses. In the next field (after colon), the user should enter a port which is used for connection (default port is 25000, but it can be changed by the server operator).

Information entered in fields User, Sample and Comment will be reflected in the files that are obtained during scanning. In the field Sample it is recommended to enter a name of the studied sample — this name will appear as a part of file name that will be obtained. In the field User, the user's name can be entered. This name, with a string entered in the field Comments, will be stored in a text header of the files that are created during scanning. One can also change the entered name, sample name and text content of Comment field. A way to do it is described in 2.2.7 section.

Press the OK button after the fields of this window are filled in. This will start connection to the server. In case a wrong address is specified, the connection will be unsuccessful and buttons Client and Master on the SPM instrument panel will remain not drowned. If one tries to connect as a Master to the server which already has somebody connected as a Master, the connection will occur in the Client mode. In the case a Master connection is successfully established, both buttons will be drowned.

After a Client connection is established, the current scan parameters window will be shown (see fig. 2.3). This window is for observation only. In Master mode, a window with scan preferences will appear. This window allows one to change the scan parameters (fig. ??). Scanning can now begin, after the feedback gains and other important parameters are set.

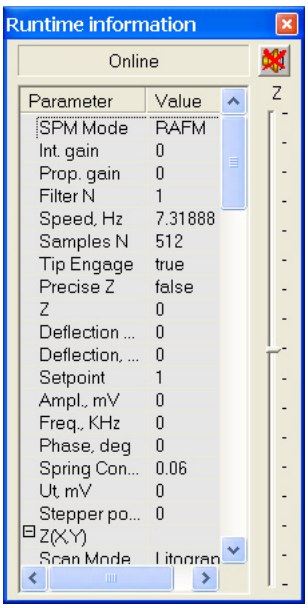


Figure 2.3. Current scan parameters.

2.2.2 Scan parameters

All scan parameters can be configured in the Parameters window (fig. ??). The program opens this window automatically when one is connected as Master. If the window is absent for some reason, it can always be called back by pressing button on the instrument panel or by selecting SPM/ Parameters command menu. All parameters that were set by the user are checked and changed by the program to be more accurate according to calibration constants that were obtained from server. Thus if there was no connection to the server, the parameter values that are displayed may not correspond to the real parameters. To get the real ones select SPM/Retrieve parameters command menu.

If the parameters are changed by entering the numbers from keyboard, to apply the values entered one needs to press Enter or push the Apply button in the parameters window. If it happens that value entered is unallowable, the program will change it by substituting the closest allowed value. If the parameters are changed by pressing buttons with arrows, parametres are checked and transfered to the server automatically.

The Client part of "FemtoScan" software allows to control the microscope while operating in three different scanning modes - tunneling mode(STM), atomic-force mode (AFM) and resonance atomic-force (RAFM). To select the mode of microscope operation, use SPM Mode field - which can be found in left upper part of the Parameters window.

In the left part of the Parameters window, main feedback parameters that are important during surface scanning and sample landing can be found:

- It — bearing value of tunneling current (STM mode).
- F — bearing value of interaction force (AFM mode).
- Ut — voltage on a tunneling gap (STM mode).
- Defl. — resonance deflection amplitude value, that program will adjust Deflection amplitude to during cantilever tuning (RAFM mode).

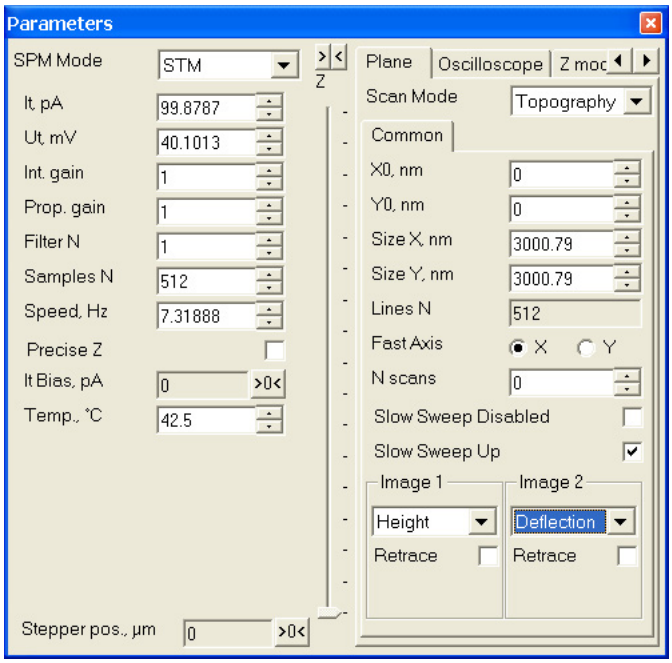


Figure 2.4. Scan parameters. STM mode of operation.

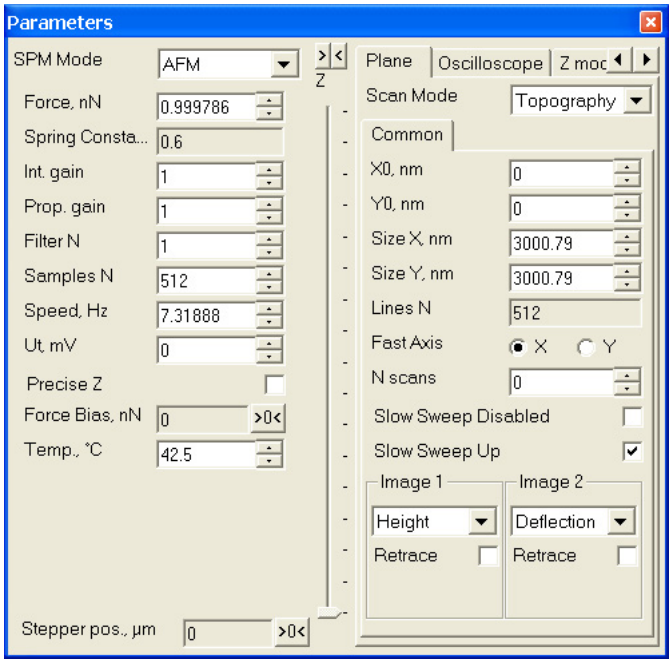


Figure 2.5. Scan parameters. AFM mode of operation.

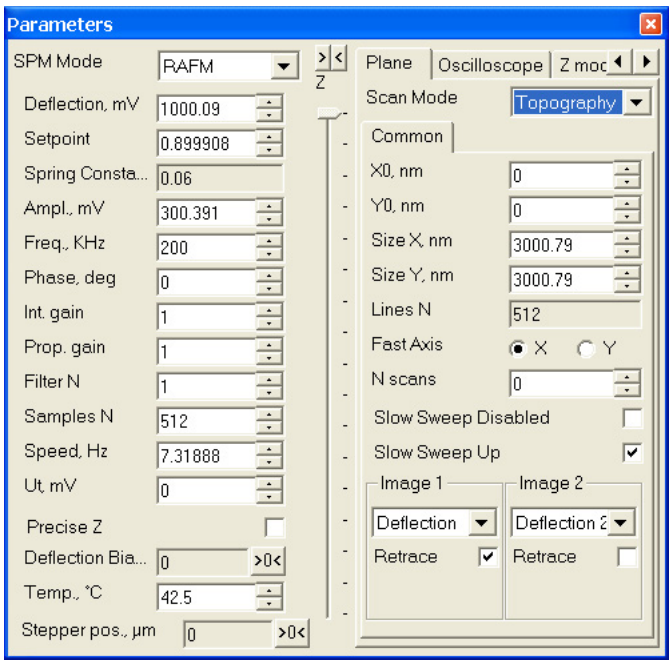


Figure 2.6. Scan parameters. Resonance AFM mode of operations.

- Setpoint — a coefficient which is set a bearing value for feedback signal (RAFM mode). This value evaluated by following equation $Defl_{sp} = Defl * Setpoint$.
- Z ampl. — modulation amplitude (RAFM mode).
- Z freq. — modulation frequency (RAFM mode).
- Phase — phase shift bearing signal for phase detector (RAFM mode).
- Int. gain — feedback integral gain.
- Prop. gain — feedback proportional gain.
- Filter N — number of measurements on which signal is averaged automatically. Value 1 corresponds to no averaging. Fractional values are possible.
- Samples N — Number of points in a scan line.
- Speed — scanning speed, measured in number o lines per second.
- Temp — sample temperature (if a temperature controlled sample table is used).

Below the feedback parameters are indicators of current microscope mode of operation and stepper motor counter. This counter can be reset by pressing "¿0¡" button. In the middle of the parameters window is a slider that shows the current position of Z-axis of the piezomanipulator. It is the same as in Current Parameters window (see fig. 2.3).

The rest of the parameters are grouped by tabs and can be seen in right part of the window.

Plane tab

On this tab, the user can set scan parameters corresponding to surface scanning Z(X,Y). Scanning can be perfomed in several different modes. Scanning mode can be set using falling list that is in the upper part of the tab window. Depending on the mode selected, one or several second-level tabs will appear. The first of these tabs contain general surface scanning parameters, the rest - parameters that are specific to the chosen scanning mode.

On a Common second-level tab following values can be set:

- Xo, Yo, Size X, Size Y - coordinates of left bottom corner of a scan window and its size in X and Y directions (see fig. 2.7). All these values are sent to the server only at the beginning of scanning process and do not change during scanning. To enter new values, the user should stop current scan, enter new values and then start scanning again. Scan window dimensions have a higher priority than bottom left corner coordinates and if the scan window dimensions become rather large, the bottom left corner coordinates decrease automatically.

  "FemtoScan" program doesn't allow scan window to leave a piezomanipulator dynamic range. Point with (0,0) coordinates is a center of a scan window of maximum size. If user chooses maximum size for the scan window Xo and Yo take maximum values automatically.

- Steps/lines — number of points in a scan line and number of lines in surface image. This field is inaccessible for direct editing. User can use Samples N field on Common tab to change number of points in a scan line. Number of lines in the scan is calculated from Size X Size Y parameters ratio.

- Lock button makes the Steps/Lines ratio constant. In other words, it constrains the scan window proportions. If this button is drawn, Size X and Size Y parameters will change simultaneously.

- Scan X-Y — scanning direction. It is possible to form image scan in two perpendicular directions - along X-axis of piezomanipulator or along Y-axis of piezomanipulator. This item allows to choose this direction.

- Disable the vertical sweep — this item disables vertical sweep - in this case the probe doesn't move along slow, vertical axis. Instead, it moves along the same line repetitively (although in the scanning window this line will be moving). All the images will be drawn in the same direction of slow vertical sweep.

- N scans — State how many times the surface should be scanned. If the word "continuous" written in this field then scanning process will last until the user stops it.

In the two frames — 1st image and 2nd image — parameters for the 1st and the 2nd image that concern the same surface scan are grouped. Inside both frames, the same parameters are available.

- Drop list, consisting of Height, Deflection, Friction and other data types (in the 2-nd image frame there is None in addition) sets what data is to be be sorted in this image. If the Height item is chosen, then surface profile data will be represented in the image. In case the Deflection item is chosen, the signal of deflection from bearing value (error signal) will be shown. Friction shows horizontal deflection of cantilever (AFM and RAFM modes). Intensity — total signal that came from photodiode (AFM, RAFM). Phase — signal from phase detector (RAFM). Channel 4,5,6,7 — additional data channels. None — will show nothing. If this item is chosen program wouldn't show the corresponding window.

  If the data is obtained from an auxiliary device connected to a COM-port enabled on the server, then Auxiliary data tape will appear on the list.

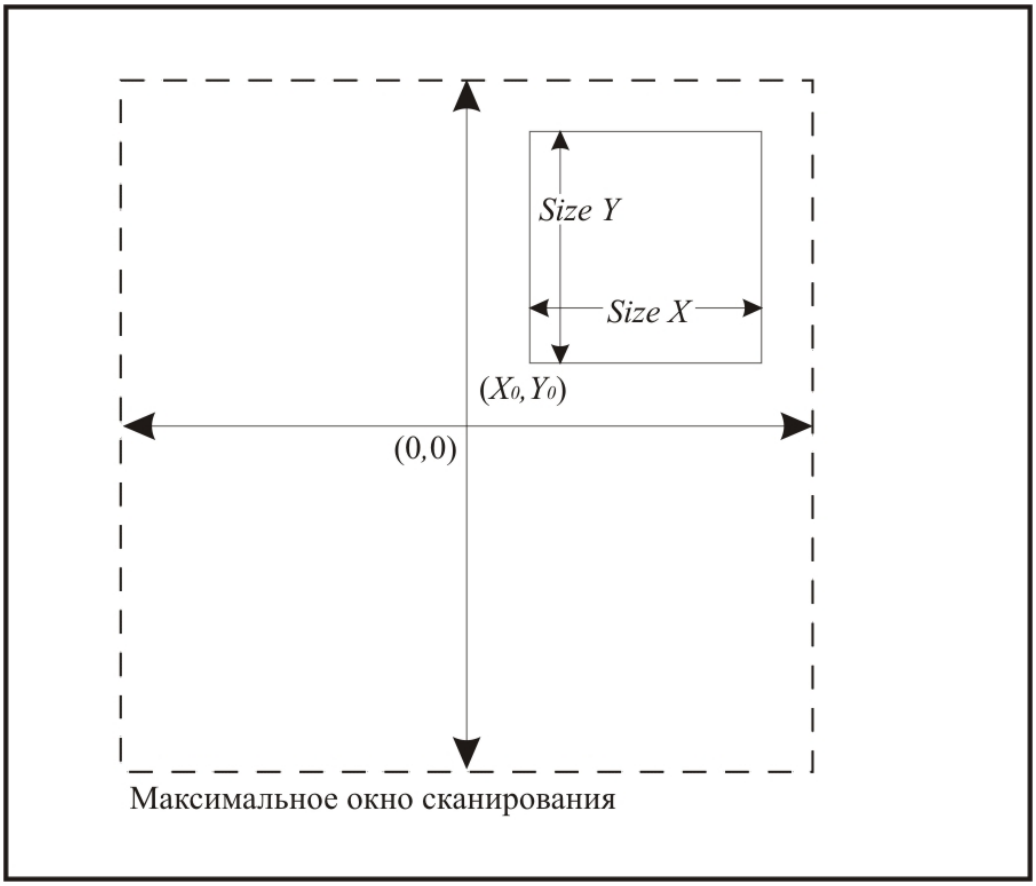


Figure 2.7. Scan window dimensions.

- Retrace — Image will contain data that is obtained during backward movement of a probe.

Apart from these parameters, the Common tab can contain some additional parameters (depending on scanning mode). In this version of the software, the following scanning modes were realized:

- Topography - usual mode of surface scanning.
- Dualtrace - scanning mode when every line is scanned twice. Feedback parameters for this mode can be configured on the tab Dualtrace. If this option is chosen, two additional check boxes appear in Common tab - "2nd trace" that allow the result of the line's second scan to be shown.
- Interleave - scanning mode when every line is scanned twice, and the second scan is preformed by repeating a profile that was obtained during first scan of this line with addition to some displacement on Z-axis. This mode allow a tip to "fly" over the sample at the specified height. This height (or displacement on Z-axis) can be specified on a Interleave tab. Negative displacement corresponds to increase in distance between tip and a sample. On the Common tab two additional check boxes appear - "Interleave" – that allow the result of interleave scanning to be shown.
- Lift - a mode in which whole scan window is rescanned for the second time by lifting the tip over the surface. This operation goes on in two stages. At the first stage, the selected region is scanned with the surface height registration during both the forward and backward movement of a probe (Height/Trace and Height/Retrace). During the second stage, the probe moves at some constant vertical displacement along the plane that corresponds to an average surface slope (that was calculated by least-square analysis method using the data obtained during the first stage). The vertical displacement (offset) can be set using Lift tab. Negative displacement value corresponds to to increase in distance between tip and a sample.
- Lithography - lithography mode. Lithography can be performed in two modes - lithography by a probe (Z), and litography by a voltage (Ut). On the Litography tab user can choose Mask image, litography mode and parameters for probe-sample interaction during lithography process. By pressing the Select button, the user can call a window that allows to choose mask image (fig. 2.8).If mask dimensions (in points) doesn't coincide with dimensions of scanning region then there are 3 possibilities: 1) Mask resolution will be changed; 2) centers of the mask and the region will be superposed; 3) Dimensions of scanning region will be changed to dimensions of the mask. In the Z mode, the scanning goes in two stages. During the first stage, surface profile in forward (trace) and backward (retrace) direction is acquired. During the second stage, the average slope plane is calculated and a scaled image mask scale with Z offset from 0 to Z is added to this plane. A probe during scanning traces the surface obtained at the second stage.

  In the Ut mode, a line profile from the mask image is transferred to the Ut DAC. The mask is scaled by the Z-axis to make all mask values fit the region from 0 to Ut . Then, the mask values shift to Ut offset.

It(Z) tab (STM mode), F(Z) tab (AFM mode), D(Z) tab (RAFM mode).

Within these tabs, similar by composition, the user can set the curves containing the parameters for It(Z), F(Z) and D(Z) dependences:

- Xo, Yo — coordinates of a point in which the dependence will be obtained.

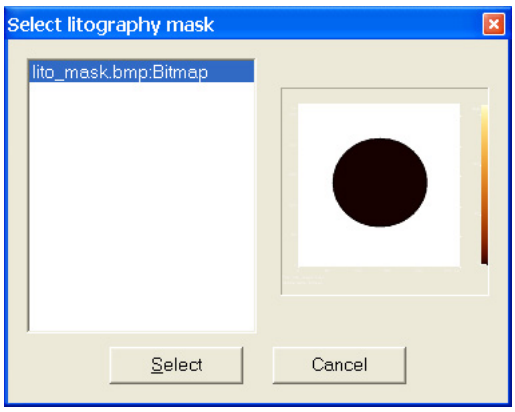


Figure 2.8. Selecting a mask image for lithography.

- Z start, Z end — initial and final probe positions on the Z-axis. Positive value corresponds to probe approaching the sample . These values are counted from the probe current position that is defined by interaction force (F) or the tunneling current (It).
- N Scans — Number of curves to be obtained. If some number is set in this field, the corresponding number of curves will be measured in forward and backward direction. They will be averaged during the acquisition process. If word "continuous" is set in this window (it can be set by entering 0 value), then the curves will be obtained continuously, without averaging.

It(Ut) tab (STM mode)

Parameters here are similar to those on F(Z), D(Z) and It(Z) tabs, but instead of Z start and Z end items there are Ut start and Ut end items. These items set the initial and final values for potential difference on a tunneling junction. The distance between the probe and the sample is defined by the bearing current.

Tuning tab (RAFM mode)

Parameters of the cantilever resonance tuning can be configured in the Tuning tab. In the Tuning mode, Deflection-Frequency and Phase-Frequency dependences are obtained. F0 and F1 parameters define the initial frequency range. If the N scans field is set to a "continuous" state, the manual tuning is preformed. In other cases, resonance is tuned in the automatic mode. In the automatic mode, the program acquires 'N scans' number of resonance curves and averages them. Then, it chooses the highest resonance peak and tunes the modulation amplitude in such a way that makes resonance amplitude signal equal to value set in the Defl. field (see 2.2.2). The frequency range decreases until the amplitude values at the ends of current frequency range exceed half of the resonance amplitude.

In the manual tuning mode amplitude-frequency dependence is obtained continuously and the user should choose the required resonance peak by placing it between two cross-like pointers (see fig. 2.9) and pressing the Zoom In button. Then, the program sets a new frequency range and changes modulation amplitude in a way that maximum amplitude signal in this range becomes equal to the value defined in the Defl. field. Note that the zero-level of the resonance amplitude is set by the program using the first amplitude-frequency dependence scan. Therefore, if the tuning has been started with a very narrow frequency range, errors may occur in zero amplitude estimation. Due to the wrong zero level, incorrect modulation amplitudes will be calculated during the tuning.

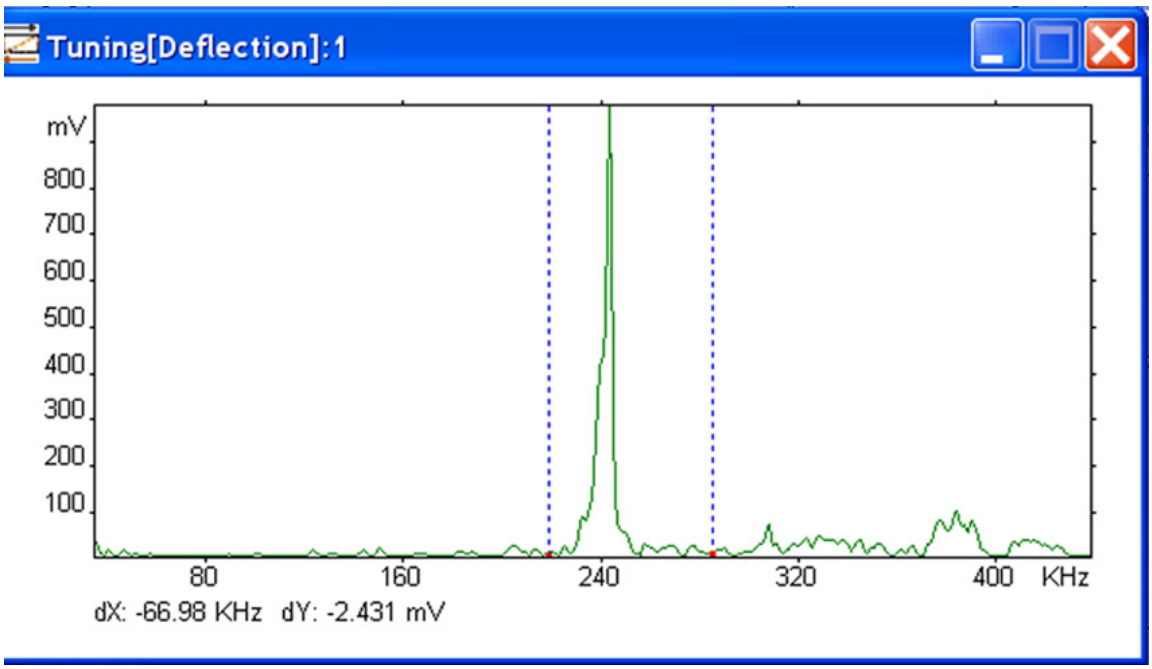


Figure 2.9. Resonance tuning.

Oscilloscope tab

This tab allow user the to configure oscilloscope.

- Data type — identifies the data type that is shown in an oscilloscope window. This can be a topography profile data (Height), a feedback error signal (Deflection), one of the signals from the second ADC (Friction, Intensity, Deflection II, Phase, Channel 4-7) or a signal from computer COM-port (Auxiliary).
- Osc. mode — identifies the mode of oscilloscope operation. In the Standard mode, it simply shows a chosen signal. In the Z Modulation mode, the program sends a rectangular pulse, the duration of which is equal to half of the sweep. If the Height data type is chosen, the red step will show an ideal response profile.

  In the Stand. abs. (Standard absolute) mode, the feedback is disabled and if the user chooses Deflection signal to be shown, then the absolute value of signal from the first ADC will be represented in the oscilloscope window (in STM mode this will be a tunneling current value, in the AFM mode - difference in laser beam intensity between upper and lower photodiode sectors, in the RAFM mode - the mean square of this difference).
- Z ampl. – modulation amplitude that is used in Z modulation mode.

Controllers tab

This tab can be used to set values for additional devices — two ADCs and a frequency generator.

2.2.3 Surface scanning

When the connection with the server is established and all necessary parameters are configured, it is possible to start the scan. First, check the slider position (found in the middle of the Parameters window). This slider shows the current position of the piezomanipulator's Z coordinate (that will be represented as a height on the final image). If feedback parameters are set correctly and a tip is not landed on a sample this slider should be in the bottom position.

Sample landing

A sample-to-tip landing can be started by selecting Landing menu command, that can be found in SPM/Start menu. The same menu can be called by pressing button. Remember that the button's menu is equal to that of the SPM/Start.

After executing the Landing command, the "Landing" caption appears in the status string of the Parameters window and Stp. motor value will start to increase. This value shows the number of steps that were taken by the stepper motor (every step is equivalent to 30 nm). When the landing is completed, a "Feedback" caption will appear in the status string and the slider will be located somewhere in between the scale. If the "Feedback" caption is shown in the status string, but the slider is still resting in bottom position, this means that the landing has not been performed yet, and the microscope has treated an accidental spike as a feedback signal. If after a continuous landing (usually it means that number of stepper motor steps is greater than 500), the surface remains unavalable (feedback haven't been activated), a "Landing failed" message will appear. This message proposes to continue landing. The "Ok" button will execute the command to continue.

Starting scanning process

If landing was successful, the surface scanning can be started. This may be done by selecting the /Z(X,Y) Scan item from the Start button menu. Depending on the configured parameters, one or two windows (see fig. 2.10) will appear after execution of the Z(X,Y) Scan command. During the scan, a bar that shows the current scanning line is runs on the image. When a new image is obtained, it can be opened in new window or ignored (see section 2.2.7). After completing the image, the scanning process is continued in the same window, but in a backward direction. Aa a feature of the software, the user can process the images during the scan.

Changing the size of scanning window

By using the Scan/ Zoom In Scan/ Zoom Out or and menu commands buttons, it is possible to increase or decrease the size of a scanning region. To decrease scanning region size, select the region of interest and press Zoom In ()button. New image will correspond to the chosen region. To increase scanning region size, select the region to which the current window will correspond on a new image and press the Zoom Out () button. In both cases, the scanning process will be continued in a current window, but with the new parameters. At the same time, the values in the Parameters window will change.

If button "Lock" on the Plane tab is drowned during the region selection, the user will be able to select regions with side to side ratio that is indicated in the Steps/lines field. If the "Lock" button doesn't drown, a region of any size may be selected.

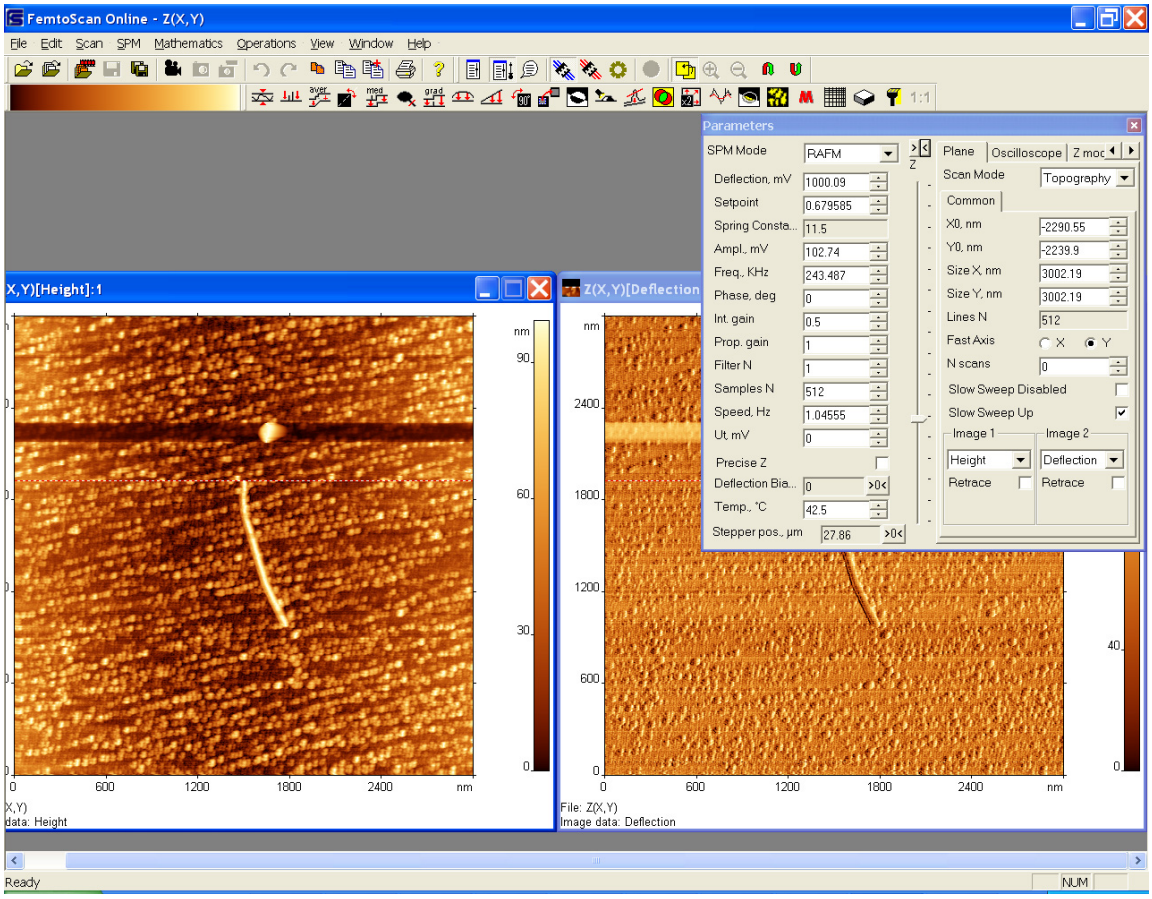


Figure 2.10. Surface scanning.

Moving the scanning window

To move scanning window to a different location on the studied surface, select the Scan/ Offset menu command or press the button and select the Offset command. The mouse pointer changes its appearance to crosshair-like. Aim this pointer to a desired location and left-click the mouse (the centre of the image will be defined to this location). The scan will continue in a current window, but with new parameters. At the same time, the values in the Parameters window will change.

Restarting scanning process

If the obtained image is not satisfactory, and a new image of the scanned region is required without waiting for the current scan to finish, press the or the button. The same commands are accessible from Scan menu — Rescan Up and Rescan Down.

Adjusting sample table Z-position

If the sample gets too far away from or comes too close to the tip during scanning due to drift or other causes, it is possible to lift or to lower it using commands for single-step approach/retraction. To lift the sample on a single step (approaching), one can press button. To lower it to a single step (retraction), press .

Note: Mechanics always have some delay; hence, the table can stand still for the first few steps.

Stopping the scanning process

To stop scanning, press or select SPM/ Stop Scan command. Take into account that the windows cannot be closed during the scan.

Powering stepper motor off

The stepper motor can be powered down by the button. This button appears on instrument panel only if this feature is enabled on the server.

Fast probe retraction

The microscope allows to retract a probe by using the piezomanipulator. The probe that is to be retracted by piezomanipulator stays safe because in this state, it is harder to inflict damage. This retraction can be done by clicking the button. The stepper motor is not used during this manipulation. The button is reset automatically when the scanning process starts.

2.2.4 Obtaining It(Z), It(Ut), F(Z), D(Z) curves

The ser can start obtaining curves by selecting the / F(Z) Scan, D(Z) Scan, It(Z) Scan, It(Ut) Scan items from the start menu. As a respond to this command, a window will appear in which the obtained curves are represented. Green curves correspond to forward probe movement (trace), red curves correspond to backward movement (retrace). The curves are scaled to fit the window. If N Scans field value in parameters window differs from 0, then a specified number of curves would be obtained. Scanning result is averaged by the number of the obtained curves. If in N Scans, the ”continuous” value is set, then the scanning is carried out without averaging and scanning process runs until it is interrupted by pressing the button or by selecting SPM/ Stop Idle menu command. In this case, the result of the last scan will be stored. It is possible to obtain these curves in a specified surface point. To do this, select Scan/ It(Ut) at... or Scan/ It(Z) at...

(in STM mode), Scan/ F(Z) at... in AFM mode, Scan/ D(Z) at... in RAFM mode menu item, or a corresponding command in the menu button.

The mouse pointer will change its appearance to crosshair-like. Aim this pointer to where the desired curve should be obtained and left-click the mouse. The curve will be obtained using the coordinates that correspond to the selected starting points.

2.2.5 Oscilloscope

Oscilloscope emulation window can be called up by selecting the / Oscilloscope start button menu item. As a response, a window that is similar to the F(U), It(Z) It(Ut) curve obtaining windows will appear. The horizontal axis of this window represents time and vertical axis represents a value that is selected on the Oscilloscope tab of the parameters window.

Note: All commands from the button menu (Landing, Z(X,Y) Scan, F(Z) Scan, It(Z) Scan, It(Ut) Scan, Oscilloscope, Photo Diode) are mutually exclusive. Once one command is selected, the others will not be operational. There is only one exception - an oscilloscope emulation window can be started during surface scanning.

2.2.6 Photodiode (AFM mode)

/ Photo Diode command of the start button menu calls a window that shows the position and the intensity of a laser beam on the photodiode. If th computr monitor is near the microscope, it can be convenient to adjust the photodiode by looking in Photo Diode program window. In the View menu, Normalize by Intensity item can be checked with a tick, which will scale the beam position according to its intensity. Photo Diode window sensitivity wouldn't drop with low beam intensity.

2.2.7 Additional commands

"FemtoScan" client-program has a number of additional commands to work with during scanning. These commands allow the execution of some special operations related to microscope control and interface configuration.

Fast probe landing and retraction

To quickly move the sample along the Z-axis (for example, at the end of the experiment) use the SPM/ Move sample command. This command allows to move the sample up (to the probe) or down (from the probe) at a specified value.

DSP bard program downloading

The SPM/ Download menu command DSP executes program dowloading. This operation should be done every time the microscope is turned on. Usually, this action is pperformed by the server operator; the user can carry out this step if necessary.

Exchanging with messages

To exchange messages between the server and other clients, a special window - Chat - should be opened. This can be done by checking the Chat window item in SPM menu with a tick or by pressing the button.

In the Connected Clients field of the Chat window, all clients connected to the server are shown. In the Dialog history, all messages that were send or received by the user are displayed. The third

field is used to write a message (send message field). If the message is aimed to all clients, press the Enter key to send it. If the message is directed at specific clients, select them by clicking the mouse while holding Ctr and Shift keys, then press the Enter key. All messages that were sent appear in Message window of the server.

Images saving mode

During the scan, different actions can be carried out that affect the obtained images. The program can store the images on a hard drive, show them in separate windows or lose them alltogether.

To show the images in separate windows, the user should put a tick next to the Capture item in the Scan menu. This is equivallent to pressing the button. Found below is a description of What is to be done to store images on a hard disk.

Actions with obtained files

If the SPM/ Client options... are selected, the command menu and a window showed in fig. 2.11 will appear. In 3 bottom fields of this window one can change the information that was entered at connection. The specifics of these parameters are described in 2.2.1 section.

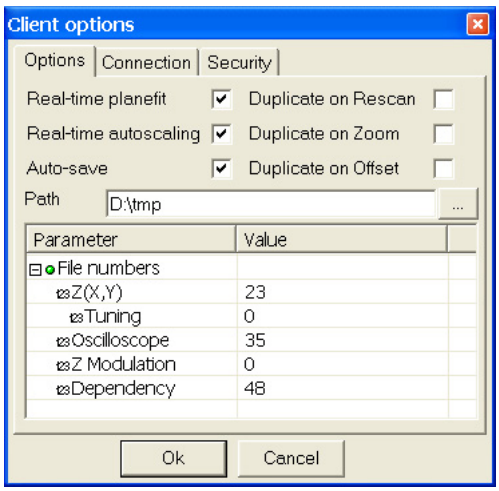


Figure 2.11. A window that contains the parameters that influence the way the programm processes the images obtained during scanning.

An AFM mode deflection parameter, that can have nm or nN values, defines units of measure for Deflection signal (AFM scanning mode). If Autosave new files item is marked with a tick, then the new files will be saved automatically in the directory that was indicated in Save to field.

Realtime planefit and Realtime autoscaling parameters are responsible for the way the data is to be represented in scanning windows. These parameters have no influence on the data. Realtime planefit calculates average slope for every scan line and subtracts it from this line. Realtime autoscaling adjusts the colour scale for every line separately. As an effect of this data, every line become "stretched" on the whole colour range. Both these parameters make small features that are on the image more visible.

The Duplicate on Rescan, Duplicate on Zoom and Duplicate on Offset commands allow the option of the scanned image to be shown in a new window. The widows will be repectedly dublicated upon Rescan, Zoom and Offset. If the user marks the Scan windows on top item, newly created windows do not cover the windows that showthe scanning process.

Changing file names during scanning

The obtained files are stored with filenames that were given according to the informationthat was entered during connection (2.2.1 section). If the user wants to change these names, it is necessary to select the SPM/ File names... menu command. A window that contains 6 pairs of fields (fig. 2.12) will appear. Every pair corresponds to the scanning mode that is specified at the left of the pair. Final filenames would consist from that is written in the pair fields and an extention that is specified on the right of the fields. When the new file appears, a number in the second pair field increased by 1. That way, the files are numbered according to their filenames.

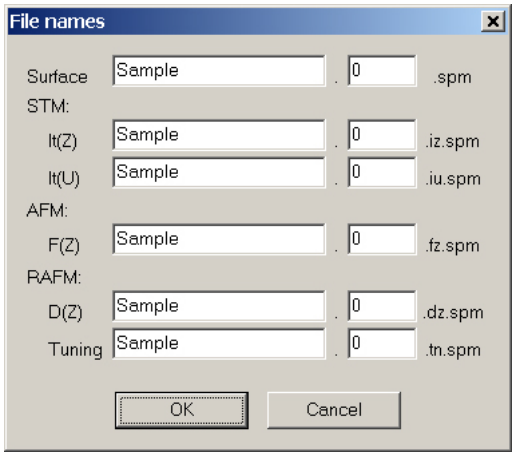


Figure 2.12. A window that allows the user to specify the filenames of the images obtained during the scan.

Turning sound on

It is possible to turn on sound signals that alert the user that the probe is too close to the sample or, vise versa, is too far away from the sample during the scan. In a Runtime information window a button (or button) is displayed. If a speaker that is shown on the button is crossed, the sound signals are disabled; if not - they are enabled. To change its state just click on it.

2.2.8 Finishing the work

At the end of the work, one should stop scanning and disconnect from the server by removing the ticks next to SPM/ Connect as Master and SPM/ Connect as Client menu items. All current parameters, as well as the calibration constants that were recieved from the server, are stored in the computer and will be loaded next time the programm is started.

Chapter 3

Image Processing using "FemtoScan" software

"FemtoScan" Software gives a wide set of functions for processing and analysis of the images. Please read carefully the Manual. The better you know the methods described here - the faster and easier you will obtain success in image analysis and processing.

The main part of the commands described in the Manual may be called either from Main Menu or from Falling Menu, which will appear after Mouse Right Button click in the image region.

3.1 Operations with files

The Software recognizes and can process data files obtained on different microscopes, including FemtoScan, Nanoscope II, III, and some others (for ref. Table 3.1). During saving Nanoscope II, III files the text heading of the file will contain only the information common with format of FemtoScan files. It is always possible to look through the text heading using menu Command View/ Parameters....

3.1.1 Files Opening and Import

To open the file press button  or choose menu command File/ Open. It is possible to choose several files at once in the appeared window using a combination of keyboard buttons Shift, Ctrl and left button of the Mouse. The last catalogue, where the files where opened or saved is remembered after user exit the program, and will be automatically restored during a new launch of the program. The current catalogue for file saving may be changed by menu command File/ Save Path....

Menu command File/ Open the same as Menu button  , permits to open not only scanning probe microscopy files, but also to import data from text ASCII files and Bitmap files (extension BMP). The data in text files must be put in three columns (X, Y and Z) for surfaces importing, or in two or one columns for curves importing.

If text file with surface data contents more than 3 columns, more than one image will be opened. The same is for text files with curves. In the columns headings after column name, separated with comma, user can put units of measurement for this column.

The FemtoScan program recognizes file format by its content, while the file extension is used just for user's convenience. It is possible to import many files at once. If the graphical file contains color palette, the height values in the imported file will correspond to palette indexes. Otherwise the height is derived from the intensity of the image.

File Format	Format File Name Extention	Data type Surface	 Curves
FemtoScan	*.spm	•	•
NT-MDT	*.mdt, *.sm2	•	•
NanoEducator (NT-MDT)	*.spm	•	
NanoScope II	*.0??	•	
NanoScope III	*.0??	•	•
Scan 8	*.tmd	•	
Park Scientific	*.hdf	•	
Molecular Imaging	*.stp	•	
Asylum Research (Igor Pro)	*.ibw	•	•
WSxM Nanotec Electronica	*.*	•	
Nanotop	*.spm	•	
Amphora (Optical data)	*.tlk	•	
WITec	*.wip	•	
Omicron	*.par	•	
LEO	*.tif (16-bit grayscale)	•	
Bitmap	*.bmp	•	
Jpeg	*.jpg, *.jpeg	•	
Text format	*.txt, *.dat	•	•

Table 3.1. Recognized Data Formats

3.1.2 Files Saving and Export

Surface and Curve data are saved using FemtoScan format. To save a file press button  or choose menu command File/ Save. To save a file at different name choose menu command File/ Save As.... To save all new or revised files take menu command File/ Save All. New files will be saved in the current directory (mentioned in the menu command File/ Save Path...).

It is possible to export images into text ASCII files, into the image Bitmap or Jpeg files, and also into 3D image file format used in Internet (VRML file format). Export peculiarities are depicted in Table 3.2. The information about inclusions, labels, scales, etc is not saved for top views for the ASCII text files. If user wants to export data to Bitmap or Jpeg format with additional information, mentioned above, he should set Export with decorations parameter to True in Export File dialog window. Also this additional information is saved for 3D images. Please note, that only Bitmap files is possible to import after the export. It is not possible to import Jpeg files and text files after the export.

Export is done by menu command File/ Export. It is possible to choose file format in the appeared window. It is worth knowing that the export of surface image may demand big amount of free space on the computer hard disk.

3.1.3 Delete File

If you regard, that a file is to be deleted from the computer hard disk, you can do it choosing one or all images in the file and taking the command File/ Delete.

Image Types	Export Format			
	*.txt	*.bmp	*.jpeg	*.wrl
Ordinary Curve and Surface Images	•	•	•	
Sections	•	•	•	
Histograms	•	•	•	
Diagrams “Enum Features”	•	•	•	
Images of Fourier Spectrum		•	•	
3D Images		•	•	•

Table 3.2. Data Export

3.1.4 Recover File

It is possible to undo all changes subjected to a file during image processing. Take a menu command File/ Revert. The file will be reload from the disk in its initial appearance.

3.1.5 Files Quick Viewing

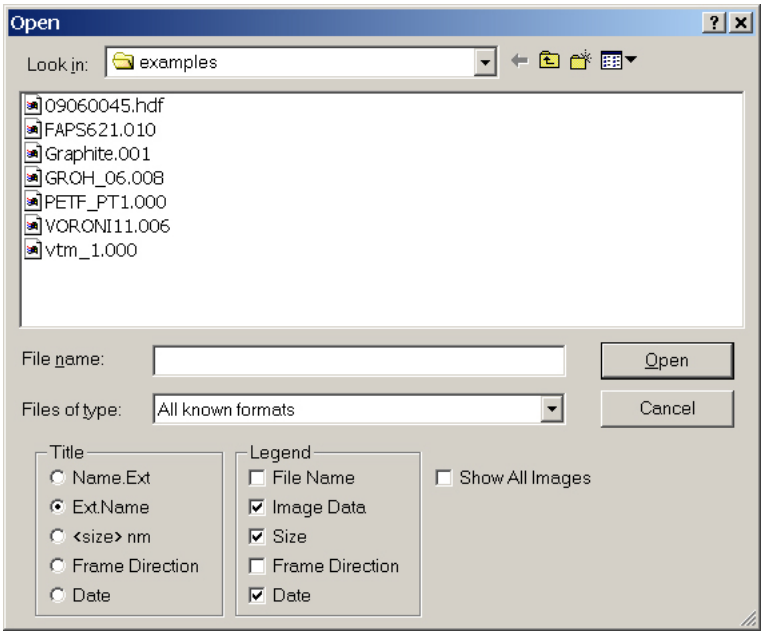


Figure 3.1. The Window for selecting the files for Quick View.

Press the button or take the menu command File/ Quick View to view quickly several files in the current directory. Select the files in the appeared window (fig. 3.1) and press the button Open. The selected files will be opened in minimized form, they will be placed evenly on the working place of the program window. The image will be restored to the ordinary size by double clicking on the left button of the mouse. Now the image can be processed and analyzed. The type of heading and legend is defined in the window for file quick selection. The information which will be shown in the heading of Quick View window is selected in the frame Title. The content of the Legend

may be defined in Legend frame. If the tick (checkmark) is put on the choice panel near the words "Show All Images", then during quick view every image which is contained in the selected file will be shown in separate window. Otherwise for every file only one first image will be opened.

3.1.6 Slide Show

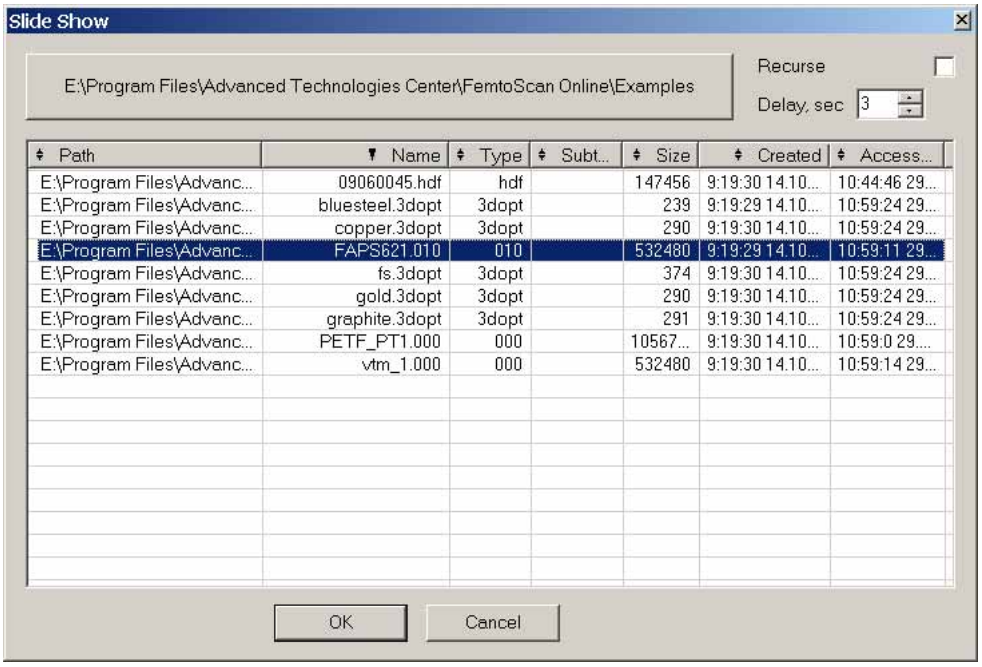


Figure 3.2. Slide Show Parameters

All the files in the current directory may be seen one by one in automatic regime using command File/ Slide Show. After choosing this command it will be suggested to select the parameters of the Slide Show (fig. 3.2). The name of the directory is shown on the button in the upper part of the dialogue window. It is possible to change the path to the files to be shown by pressing this button (the default directory is current). The field Delay, sec is used to set the time interval between the appearance of the images on the computer screen. Option, allow viewing the enclosed directories, may be selected by putting a tick against label "Recurse directories". In the center field of the Slide Show parameters dialog is a table, witch shows all associable files in chosen directory. User can remove files from the table (and from the future slide show) by pressing Delete button or by choosing Delete Selection command from the menu that appears after clicking mouse right button. Note, that files removed this way are not deleted from hard disk, but only from Slide Show list.

The images during Slide Show will appear one after another within a selected time interval. The minimal interval between images is equal to 3 sec. In order to pause/continue the Slide Show, user can press Spacebar on the computer keyboard. To exit Slide Show press "Escape". Then program opens the file, which was shown the last.

3.1.7 Working with files, containing Curves

Curves, when opened, are represented in a way same with sections (see 3.5.2 for details). So, the possibilities to work with and to represent the curves are the same with these possibilities for

sections. When user opens curves in formats, that allow multiple curves to be in one file, like FemtoScan, Nanoscope III, NT-MDT, there can be several curves represented in the same window. In this situation one curve will be active and represented with solid line. The others will be represented with dashed lines. The Fourier spectrum will be shown for active curve only. User can choose active curve by pressing Tab button.

3.2 Microscope Parameters Data

3.2.1 File Text Headings Viewing

FemtoScan and Nanoscope file formats have text headings, which can be viewed using menu command View/ Parameters.... In this case the window will be opened, in which the parameters of scanning/measurements will be shown — these parameters were written in the Parameters Window (section 2.2.2). Information about the date of file origin, user name and user's comment will also appear in the Window.

It is possible to change the comments written in the file using menu command View/ Comment.... You can write the necessary information in the text field of the opened window.

3.2.2 Changing Image Resolution

If by some reason the horizontal image scale is incorrect, you can change it easily. Select menu command View/ Resolution. This command is accessible if the window user working with is a surface image, histogram or curve/cross-section. The window shown here fig. 3.3(a) will appear, if Resolution... command was applied to image without any distance measured on the surface before. You can put there new length units and new image dimensions.

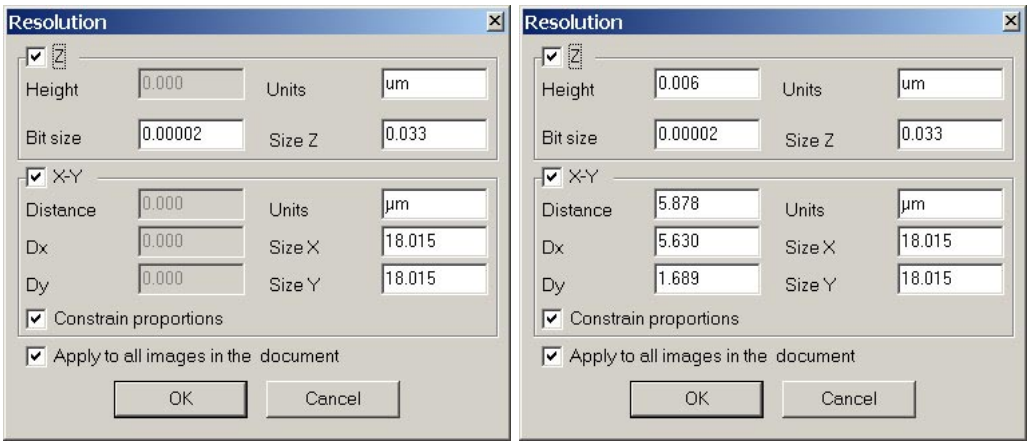
Let's look a bit deeply on the field named Bit size. In the FemtoScan file format height data (Z axis) are stored as integer numbers, two bytes in size. Program uses coefficients to convert these integers in real values. If user opens file in different format, in which height data stored not in two bytes per value format, program converts these data to program's own format, which is two bytes per value. In the Bit Size field is a height, that corresponds to one bit from the whole two bytes of FemtoScan data format.

If the options Constrain proportions is selected, then the scale in Y direction will be changed accordingly. Otherwise it is possible to change the scale in Y-direction independently from X direction. If option "Apply to all images in the document" is selected, then the scale will be changed for all images in the file. Otherwise the changes will occur only to the current image.

Some fields in a window showed on picture 3.3(a) are not active and user cannot change them. They can become active, so user can change them in case when the distance on the surface have been measured before the Command Resolution... was called, or this function is applied to a curve, section or a histogram.

If the distance on the surface was measured before the Command Resolution was called (section 3.5.3), or this command was applied to section, histogram or curve, then a slightly different window will appear (fig. 3.3(b) - in this case this function was applied to a section).

In this window in field Height one can enter a hight of an object. In case when this function is applied to section or a curve difference between marks on a dashed lines will act as such an object (see 3.5.2), and in case this function is applied to histogram a difference in heights between dashed lines (see 3.7.6). In a field Distance one can enter the distance between dashed lines on a cross-section or a curve, or measured distance on a surface, and in the fields Dx and Dy - its X and Y projections of this distance.



(a) (b)

Figure 3.3. Changing of horizontal scale of surface image. Dialog windows.

Note: If you want to change only horizontal (vertical) resolution, leave the Z (X-Y) checkbox unchecked. This will prevent program from changing vertical (horizontal) resolution as well.

3.3 Importing Images from Other Devices

Using "FemtoScan" Program it is possible to import images captured by scanners or videocameras.

3.3.1 Videocameras

The program allows to observe the images from video camera and to capture frames, which can be analyzed and processed using FemtoScan program.

It is important to select the proper driver of video device before using it. If you do it for the first time, select menu command File/ Capture.../ Video or press button . The window where it is possible to select the driver will appear. Select the driver and press OK button, then the window, showing the movie from the video camera will appear. Next time when the Command Video is selected or the button is pressed, the driver selection window won't appear any more, and the movie will be seen in a window.

The menu command Video/ Options/ Select video device... is used to change the current driver. This command works as previously described.

To obtain a frame as a picture for further analysis and processing select menu command Video/ Capture frame or press the button . A new window with a video frame will appear. But you canot analyze this image with FemtoScan program, because it is in BMP format and not in SPM format. It is necessary to convert it for further processing. Take menu command Bitmap/ Convert to spm image. Bitmap conversion options window, shown in fig. 3.4, will appear. Colors will be transferred into heights so that the height is proportional to sum of the intensities of three colors. The colors can be added at different weights as selected in this window. If the option Invert Image is selected, then the program will regard the image as negative and will perform the consequent

evaluation of the heights. The image conversion occurs after you pressing Convert button, and then it is possible to analyze and process the image.

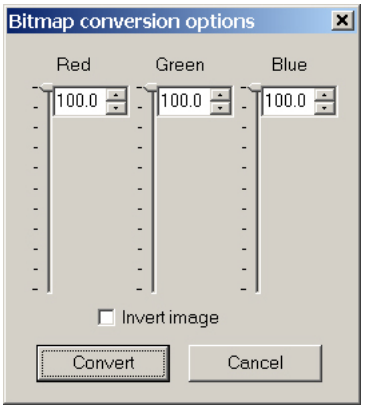


Figure 3.4. The window to select the parameters of conversion of raster image into SPM-image

It is possible to obtain images which will correspond to average of several separate frames. The menu command Video/ Capture multiple frames or button are used for this. Select this command and window in which it is possible to select time interval between frames to be averaged and number of these frames, will appear. Press the Start button to start the video frame capturing and averaging. After the program complete this operation you will see the window Bitmap conversion options (fig. 3.4) instead of the final image. Select the parameters of conversion, press the button Convert and the image in SPM format will appear.

It is possible to configure parameters available in the driver of video device during video capture using "FemtoScan" program. Menu Video/ Options is used for this. The details are not described here, because they may be specific for different video cameras. It is possible to choose to modes of video capture: — Overlay or Preview. The image will be sent directly from the video device to the video card in the Overlay mode, and will go via processor in Preview mode. The first mode is better but is not supported by all video cameras.

3.3.2 Scanners

It is important to select the proper scanner before capturing an image. Please select the Menu Command File/ Capture.../ TWAIN.../ Select Source... and choose the device in the appeared window.

Now the command Acquire..., placed in the same menu, may be taken. The scanning program, installed at your computer to operate a scanner, is launched by this command. When the scanning is fulfilled the window with image will appear in the "FemtoScan" program. Please note, that its format will be raster image. To convert it for further processing please conduct as described in previous section.

3.4 Working with palette

The image view depend much upon proper correspondence between color and height — palette. Several specially designed palettes are present in the program, still an opportunity to develop your own palette exists for a user. If the palette is absent at the Tool Bar, it can be called by putting

a tick in the Menu View/ Tool bars against Scale. The choice of current palette is done by Mouse click on the palette image using Right Button - the Menu with all palettes listed appears.

The Command Custom palette of the falling Menu calls the window of the construction of new palette (fig. 3.5). You can adjust each component color - height dependence separately in this window. The button"Smooth" is used to smooth the drawn curve. The palette can be saved using the button "Save". The saved palette can be read using the Command "Load". Press the button"Ok"and the created palette will become current.

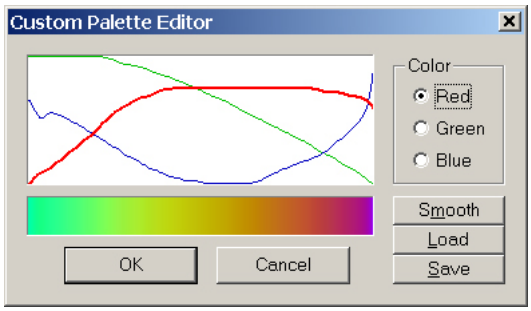


Figure 3.5. Modifying a palette

There are several modes of palette:

- Fixed Scale - in this mode the scale of palette can be precisely set by adjusting vertical dashed lines on the palette bar. If the tick stands in the menu View against Auto Refresh, then the movement of the lines will lead to the refreshment of the image in the active window in automatic way. To perform manual refreshment press the button or choose the menu command View/ Refresh. When you doubleclick the palette bar, the scale will be automatically adjusted to whole range of the image data. If you will select another image and call the View/Refresh command (or push the button), this image will be repainted in the same scale. When in the image's Preferences window (View/Preferences) the mode of Z scale is set to the "Absolute", the scale will be applied in absolute units. If the mode of Z scale is set to "Relative', the scale will be applied from the lowest value of the image.

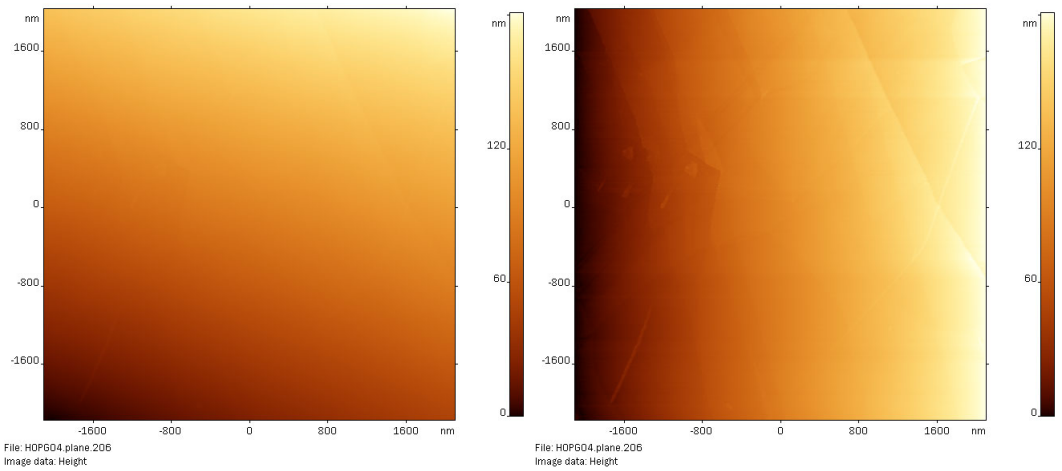
  If the image Z units are different from the orignal units of the scale (which are set when you doubleclick the palette), then the scale will be set to the fixed size, equal to the 1/2 of the possible image data range.

- Autoscaling - in this mode the scale is stretched from the lowest to the highest Z value in the image (pic. 3.6(a)).

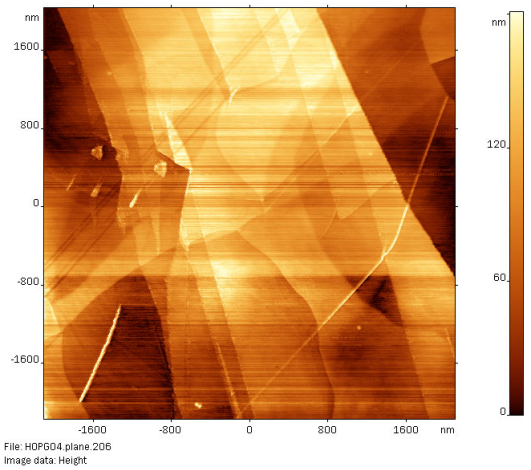
- Per-line autoscaling - the scale is stretched for each scan line individually from the lowest to the highest value of the line (pic. 3.6(b)).

- Per-line autoscaling with planefit - like the previous mode, but from the line is subtracted the average slant (pic. 3.6(c)).

If you choose one palette, it will be used for all images you open as well as for opened ones, if you refresh (reload) them. This behavior can be changed for an image, if user put a tick against the menu item View/ Remember Palette. In this case whatever palette is chosen, it doesn't affect this particular image. And, if an image was saved with menu item Remember Palette checked, it will open next time with this particular palette, which was saved with a image file.



(a) (b)



(c)

Figure 3.6. Different modes of palette autoscaling.

3.5 Cursor modes

This section also as sections 3.6 and 3.7 deals with procedures for surfaces processing. They are not available for the processing one-dimensional figures.

The click on the Right Button of the Mouse in the image field leads to the appearance of the falling Menu. The current mode of the cursor is selected in the first section of the Menu. It is defined by a tick. Select a new line to change the cursor mode.

3.5.1 Select surface region

Cursor mode Selection is switched on by default. The surface regions may be selected in this mode for further processing.

3.5.2 Sections

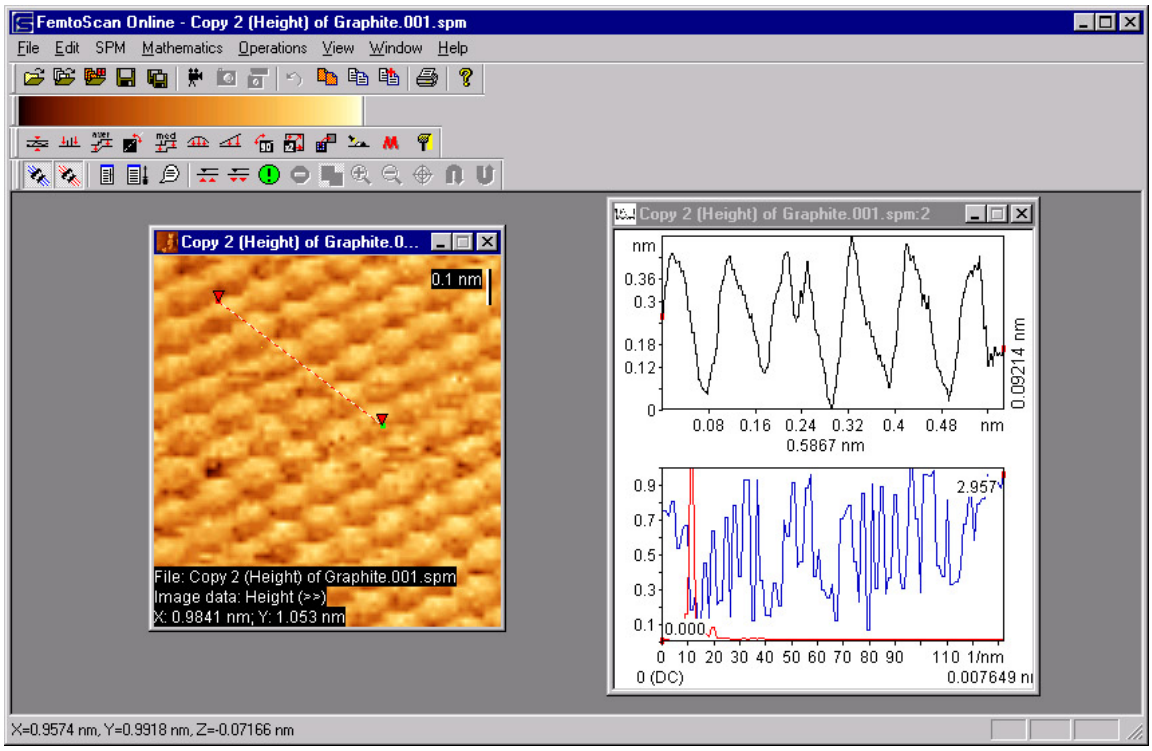


Figure 3.7. Construction of Sections.

Sections of the surfaces Section may be built in this mode. It is recommended to built sections only on Height Images. To fulfill the procedure click the left button of the mouse at the point which will be starting on, and continuing pressing the button draw the section line. The section line and the window with the image of the profile across the section line will appear after the release of the button (fig. 3.7). The section line will appear on every image which is contained in the file. It is possible to observe both section profile and its spectrum. To achieve this put a tick against option Spectrum in the Menu View when the section window is active. The red line corresponds to power spectrum, the blue line — to phase spectrum.

There are two dotted lines at the edges of the Section Window. The distances and height on the profile can be measured by moving these lines by holding left mouse button and moving the mouse. Two triangular cursors are moving along section line on the surface image, the cursors correspond to the position of dotted lines on the profile. Single right-click may change the mode of distance measurement to the mode of angle measurement and back. The values of spectrum power and phase can be obtained with similar dotted lines.

Using View/Options... menu user can choose different modes of Section representation on horizontal and vertical axis. There are two regimes to control horizontal axis - Fixed Width or Fixed Scale. With the first one when user change window size the section width will change as well. With the second one section width remains constant.

To control section's vertical axis user can choose menu item Auto, and this cause the profile to be scaled to fit section's frame. Or user can choose Fixed menu item and enter the size of the vertical scale manually.

The start and end point of the Section Line may be moved in the Surface Window. The content of the Section Window will be changed simultaneously in this case.

3.5.3 Distance Measurement

Distance Mode allows to measure the distance between points on the surface. The distance is measured as a projection on X-Y plane, the distance along Z direction is not accounted. The measured value is presented near the drawn line.

3.5.4 Isolines

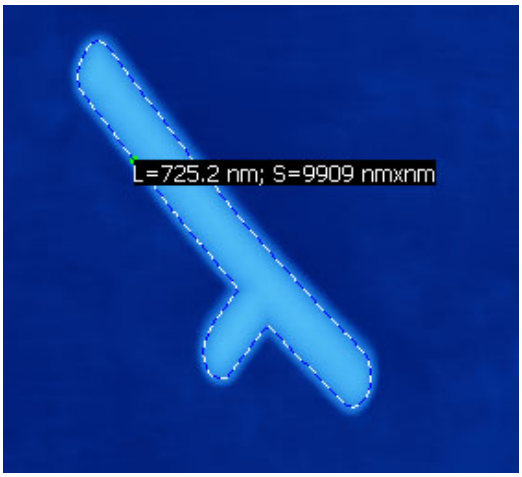


Figure 3.8. Constructing lines of equal height.

Operating in the IsoLine Mode , single click in the Image region finds the point which will define the line of equal height (fig. 3.8). The line may be abrupt during construction if the surface image is not smooth enough. The length of the equal height line is presented near. The square surrounded by the line will also appear if the equal height line is closed.

3.5.5 Angle measurement

The angle between two lines is measured in Angle Mode. The first line and the second line are built by selecting the start point with Left Button of the Mouse and moving the Mouse with a pressed Button to the end point. The angle between the line and the horizontal line is shown in the right lower corner of the Program Window when you draw this line. Also the angle in vertical direction between the selected points is shown.

3.5.6 Put a mark

The Mode Marks is used to put Marks on the Image. Mark type is defined in the Menu View/ Marks Style. If the Numbered field is selected, then the number will appear near each mark. The marks may Arrow-like or V-like. It is possible to remove a mark pointing a cursors at it until red cross (available in Mark Mode) is appear and then click it. It is also possible to delete all the marks using Menu Command View/ Clear Marks (available in all Modes) The Marks may be moved when the keyboard button Shift is pressed.

3.5.7 Drawing Curves

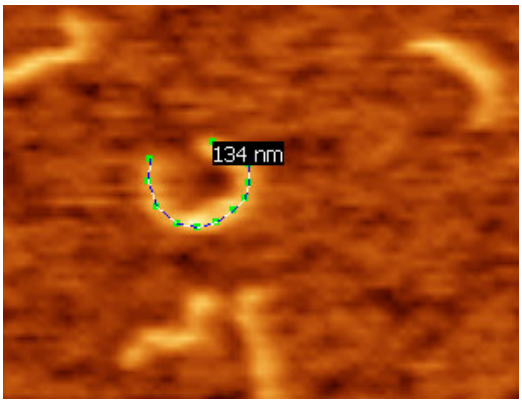


Figure 3.9. Measurement of curve length.

Curve Mode allows to measure the length of curve lines. Put the points on the line - its length will be calculated automatically (fig. 3.9). To delete a curve point a cursor at the start point of of the curve (marked by green rectangular) and press the Left Button of the Mouse. If you point the Mouse at any point of the curve and press the Left Button, then a part of the curve after this point will be deleted. The point may be moved when keyboard button Shift is pressed.

It is possible to draw a number of curves at the same time. To draw a new curve instead continuing the old one hold Ctrl button while clicking the left mouse button. All curves can be removed with the menu command View/ Clear/ Curve.

3.5.8 Line Selection

Line Selection Mode allows to select sections across the scanning line. Press the left Button of the Mouse on the line of interest - the line will be selected and the section will appear in the window. The number of the scan line will appear in the window. The scan lines are counted beginning from the lower one. The selected scan line can be moved by keyboard buttons “↑” and “↓”. If the image

contains a noisy scan line it can be deleted by the menu command Line/ Smooth . As a result of this

operation the selected scan line is substituted by the average value of two neighbor scan lines. Selected line may be substituted by the upper or lower scan line by the Menu Commands Line/ Replace to Upper and Line/ Replace to Lower .

3.5.9 Column Selection

Column Selection Mode allows to select sections across the vertical lines on the image — columns. Press the left Button of the Mouse on the column of interest - the vertical line will be selected and the section of it will appear in the window. The number of the column will also appear. The columns are counted beginning from the left. The selected column can be moved by keyboard buttons "←" and "→". If the image contains a noisy column it can be deleted by the menu command Line/ Smooth . As a result of this operation the selected column is substituted by the average value of two neighbor columns. The selected column may be substituted by the right or left neighbor column by the Menu Commands Line/ Replace to Upper and Line/ Replace to Lower .

3.6 Data Processing Functions (Mathematics Menu)

A wide set of different mathematical functions for data analysis and processing is realized in FemtoScan program. These functions can be found in two Menus — Mathematics and Operations. There is no strict division of the functions between the two Menus. Mathematics Menu Commands are mainly used for the correction of the data, while the Operations Menu Commands are mainly used for the data analysis. Mathematics menu Commands are described in this section. All listed Commands may be called also by pressing the Left Button of the Mouse on the image field.

3.6.1 Macrocommands

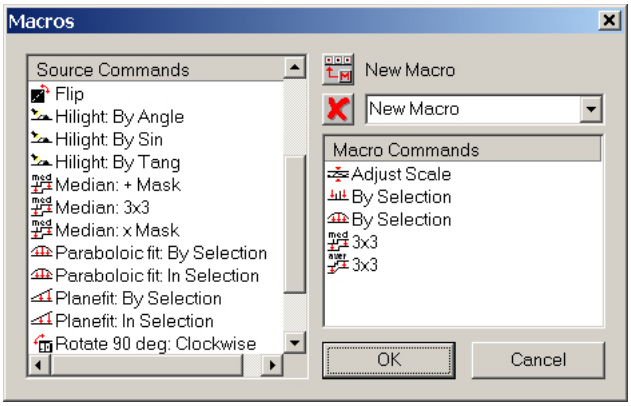


Figure 3.10. Macrocommands Window.

Macros may be created and controlled using Menu Command Mathematics/ Macros... . The window Macros with several panels appears after calling this command (fig. 3.10). A set of possible commands and corresponding Buttons (as they appear at Tool Bar) can be seen at the left panel. You can form a Macro command with a name seen above the right panel (e.g. New Macro) by dragging the Buttons from the left panel to the right one. The order of the Commands may be also

rearranged with a help of the Mouse. The current Macros may be deleted by pressing the button . The name of the Macros associated with button on the Tool Bar is shown in the upper line of the panel. The necessary Macros (if there are many) may be selected using the falling menu. You can put edited macros on the Tool Bar by pressing the Button . Created Macros are placed in the lower line of mathematics Menu after the separator. The first of them is associated with the button on Tool Bar.

3.6.2 Dewarping

Image hysteresis compensation function (Dewarping) is located in the Mathematics menu (button). THis function requires hysteresis coefficients file selection. Creation of such files is described in the section 3.7.3. File should contain data for the every axis of the image, and in the simplest case file would have two sections: `x-calibration` and `y-calibration-slow`. Standart operation sequence is looking as follows:

1. Obtaining calibration grating image. Periodical structures better to be aligned along scan axes, scan speed should match to the speed, on which studied images were obtained.

2. Building two calibration curves on the calibration grating with known distances between curve's knots (pic. 3.21). On every curve calibration file is created. During the file saving the same file name can be entered for the both curves – data will be saved to the proper section, depending on the curve orientation.

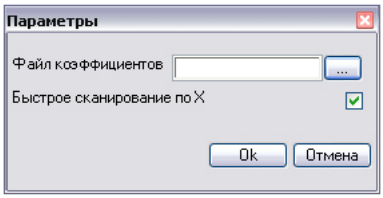


Figure 3.11. Dewarping coeficients file selection.

3. Saved file is selected as coeffincoents file in the command window (pic. 3.11).

4. Mark "Fast axis X" should be set to correct hysteresis in files, where fast scan was along X–direction.

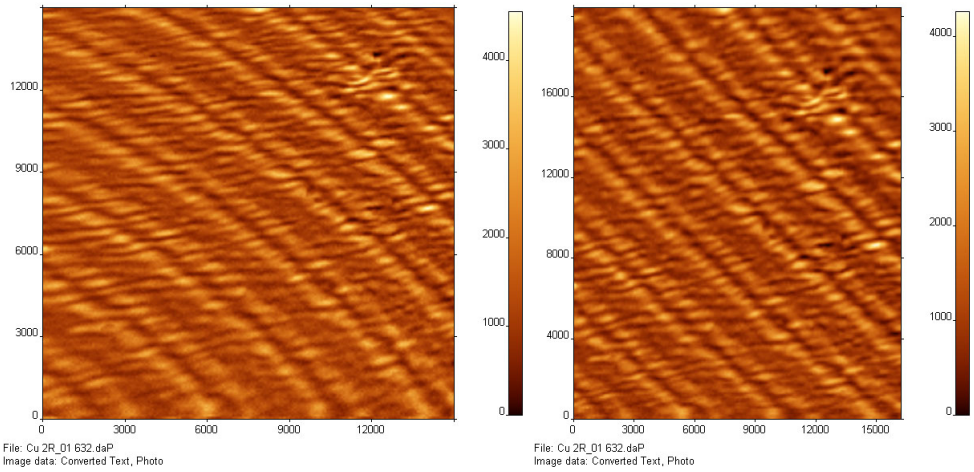
   Dewarping result is shown at pic. 3.12.

3.6.3 Scale Adjustment

Adjust Scale Function (button) is used to scale the values of image height in order to avoid the errors due to rounding or overloading during further processing. The minimal value of the height will be -16384 and the maximal value — +16383 after using this Function.

3.6.4 Averaging by scan lines

The average value of the height along each scan (line along X direction) line is calculated. Then the scan lines are put upper or lower so that in the new image the average height along each scan line is the same. This averaging is performed using Command Adjust Scan or button into two ways: By Selection and In Selection . The difference between these two ways will appear if you



(a) (b)

Figure 3.12. Dewarping.

select in advance a region on the surface. In Selection option will perform averaging only in the selected region, the outer surface will not be modified. By Selection option will average all the image according to the data which is placed in the column, the width of which is equal to the width of the selected area. The Button on the Tool Bar corresponds to the option By Selection.

3.6.5 Averaging

The averaging is fulfilled by the Command Average. The averaging is performed by standard matrix 3×3 and 5×5. The averaging by 3×3 matrix is available through the button on the Tool Bar.

3.6.6 Reflection

If you have obtained the two images of the same surface region while the low scan directions were into two different directions (along X axis and along Y axis), then it is possible to check the coincidence of the images using the mirror reflection of one of them. The Command Flip (Button) fulfills the mirror reflection of the image along X=Y axis.

3.6.7 Median filtering

This operation is fulfilled by the Command Median. The template for it may be either square 3×3 (Button), or have the following configurations: $\otimes$ or $\oplus$.

3.6.8 Morphological Filters

All Morphological filters are based on two operations — *dilation* and *erosion* . They are defined in the following way. Suppose you have two accidental set of points in discrete two dimensional space: $\{(m,n)\}$ and $\{(p,q)\}$. Lets define a function for these two sets $A(m,n)$ and $B(m,n)$, which we will call as objects A and B. The operation *dilation* (extension) will be defined as following:

Filter	Description
Smooth	$Smooth(S,F) = Close(Open(S,F),F) = E(D(D(E(S,F),F),F),F)$
Contrast	$Contrast(m,n) = \frac{D(m,n)-E(m,n)}{65535} \cdot (S(m,n) - E(m,n))$ — structural element F is used here during the calculation of *dilation* and *erosion* .
Min	The new value for the point is taken as minimal one among the value of this point and eight neighbor points. In the terms of morphological operations — this is an operation *erosion* with a structural element 3×3, where all the value are equal to zero
Max	The new value for the point is taken as maximal one among the value of this point and eight neighbor points. In the terms of morphological operations — this is an operation*dilation* with a structural element 3×3, where all the values are equal to zero.
Dilate	Operation *dilation* with structural element F.
Erode	Operation *erosion* with structural element F.
Open	$Open = D(E(S,F),F)$
Close	$Close = E(D(S,F),F)$
Gradient	$Gradient = \frac{1}{2}(D(S,F) - E(S,F))$
Laplace	$Laplace = \frac{1}{2}[(D(S,F) - S) - (S - E(S,F))] = \frac{1}{2}[D(S,F) + E(S,F) - 2 \cdot S]$

Table 3.3. Standard morphological filters realized in FemtoScan

$$D(A,B)(r,s) = \max_{(j,k)\in B}(A(r-j,s-k) + B(j,k))$$

Operation *erosion* looks as following:

$$E(A,B)(r,s) = \min_{(j,k)\in B}(A(r+j,s+k) - B(j,k))$$

It is common to call in the above expressions A as an image, and B as a structural element. The surface plays the role of the image in the morphological filters used in FemtoScan program (lets define it as S), while the object F (shown below) most often plays the role of structural element.

$$F = \begin{vmatrix} 0 & 1 & 0 \\ 1 & 3 & 1 \\ 0 & 1 & 0 \end{vmatrix}$$

The value 3 correspond to the coordinate $(0,0)$.

Standard morphological filters available in the FemtoScan program and their description are shown in the Table 3.3.

Besides traditional morphological filters the program contains the filters specially designed for scanning probe microscopy. For details about this filters please refer to the articles by J.S.Villarrubia, Surface Science 321 (1994) 287-300 and J.S.Villarrubia, J. Res. Natl. Inst. Stand. Technol. 102 (1997) 425.

The calculation of tip of maximal blunt shape which will not put distortions into the image (or a selected part of the image) during tip scanning is launched by the Command Non-distorting tip. In other words it is so as if it is regarded, that the obtained image is a precise copy of the scanned surface and one try to find the tip which can perform such an exact scanning.

The filter Blind tip estimation also calculates the tip of the maximal blunt shape, which can be used for obtaining this image (or a part of it). But the condition on non-distortion is absent

	h_x	h_y
Gradient	$\begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & -1 \\ 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & -1 & 0 \end{pmatrix}$
Prewitt	$\frac{1}{3}\begin{pmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{pmatrix}$	$\frac{1}{3}\begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{pmatrix}$
Sobel	$\frac{1}{4}\begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix}$	$\frac{1}{4}\begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}$

Table 3.4. Matrices used in the calculations of the first derivatives

now. There is a new restriction on the tip shape. It is quite reasonable, that if the tip apex is of some curvature, then on the image will never appear the protrusion with less curvature. Thus the protrusions are the limitation for the tip shape.

The window with progress indicator appears after the launch of Blind tip estimation filter. The iterations are performed during the filter operation and it is expected, that once the result of the next iteration will be the same as the previous one. The filter operation is stopped when no changes in the tip shape occurs during the iteration. It is possible to stop the filter operation in advance. Press Cancel in the Window of the launched filter to stop the filter operation. You will the shape of the tip for the iteration processed when the button Cancel was pressed.

By command Continue blind tip estimation... the window with list of all open in the program surface images appear. Please select the window, where the tip shape estimation is already stored and press Select. The algorithm of this filter is the same with a little difference, that the initial iteration will not be a plane but the selected shape estimation.

By command Erode tip... The window appears, in which it is necessary to select tip shape estimation among all opened in the program. The filter fulfill the operation *erosion* over the current image using a selected tip as a structural element.

3.6.9 Differential filters

The derivative along x axis (y axis) for a discrete function is presented as $h_x \otimes S$ ($h_y \otimes S$), where $\otimes$ means convolution of two functions, h_x and h_y — some discrete functions (matrices), S — function to be derivated. Knowing the derivatives along two axis it is easy to find the module of gradient as a square root of the sum of two squares. Three variants for the calculation of gradients are available in FemtoScan program: Gradient, Prewitt and Sobel. The difference between them lies in the used matrices h_x and h_y. They are shown in the Table 3.4.

Laplace Filter calculates the laplacian in the following way: $Laplace(S) = h \otimes S$, where

$$h = \begin{pmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

3.6.10 Subtraction of surfaces of average slope

It is possible to subtract the surfaces of two types — surface of the first order (plane), and surface of the second order. The corresponding Commands are called by Planefit (button) and Paraboloic Fit (button ). If you have select a surface area in advance, then there are two possible

ways to fulfill an operation — to process only the selected area (In selection), or to process the whole image by using the slope coefficients derived from the selected area (By selection). If the area is not selected, then the both variants are equivalent.

3.6.11 Rotation

The image rotation is performed by the Command Rotate 90 deg/ Clockwise (button) and Rotate 90 deg/ Counter-Clockwise. If the image has a rectangular form, its dimensions will be changed accordingly.

3.6.12 Linear spline

FemtoScan software can calculate bilinear cubic splines for the surfaces and subtract splines from the surfaces. To construct a spline the surface divided into rectangles, sides of which user can input in dialog window. This window appeared when user choose command Spline/ BSpline stride.... For every rectangle average surface height is calculated, and spline constructed on the central point of the rectangles, where Z-axis values are average heights calculated before. To construct a spline for a surface or its part, choose command Spline/ Bilinear spline. To subtract spline from the surface or its part, choose command Spline/ BSpline fit. Note, that command BSpline fit calculate spline, subtracted from the surface, and it do not use spline, calculated with the command Bilinear spline.

3.6.13 Height from interference figure

FemtoScan software can evaluate height and slope of hillock at the surface of crystal from interference figure. This function can be used by choosing the command Height from interference figure in menu Mathematics or button .

At first it's necessary to mark a section or sections, which slope is wanted to be found. For this purpose can be used one of two cursor modes: Section or Distance (to learn about cursor modes see part 3.5).

Then the function can be called. This call evokes the appearing of menu with parameters (see 3.14): wave length and threshold, which assign minimal possible amplitude at interference figure in percents of maximal existent amplitude.

First evaluation uses standard parameters. After changing of their values programm will make new evaluation. Resulting table (see 3.15) contains drops in height at selected sections, distances between the ends of sections and angles of drops, if it is possible to calculate (if units for height and X-Y are convertible).

3.6.14 Threshold filtering

The Command Threshold calls the Window, shown in fig. 3.16. The threshold level (as a part of the maximal height of the image) may be defined here. In this case the surface regions which are lower than threshold image will be deleted — their height will be changed to the minimal one on the surface. If the option 2 levels only is selected, then the surface regions higher than threshold level will be changed to the maximal one in this surface.

3.7 Data Analysis (Operations Menu)

The Commands presented in Operations Menu (all of them are also available by Clicking Right Mouse button on the image area) allows to obtain different information about the surface, add/subtract images, to present them in more clear form.

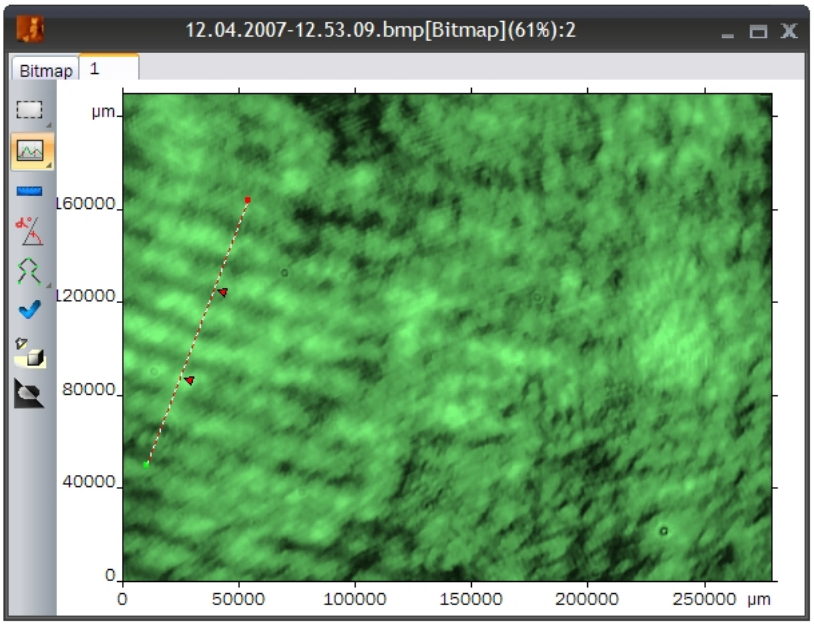


Figure 3.13. Section at interference figure.

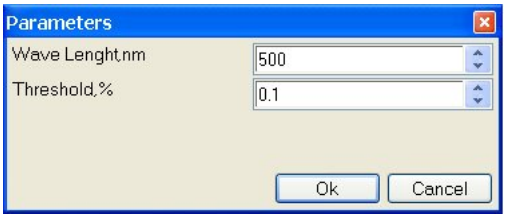


Figure 3.14. .

Figure 3.15. .

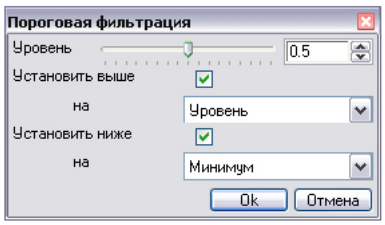


Figure 3.16. The Window of Threshold Level Selection

3.7.1 Reconstruction of 3D Images

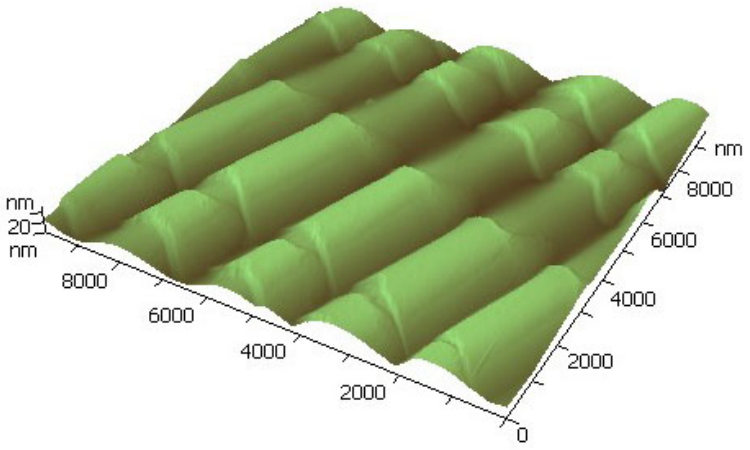


Figure 3.17. 3D Image.

The program allows to build three dimensional images of the surface. Select the Command Build 3D View to do it. Different operations may be performed with the reconstructed 3D image.

- The scales on all coordinate axis may be shown or removed. This is controlled by the tick against words Show legend in the Menu View.
- It is possible to show or to hide marks, curves, isolines and sections that was drawn on the surface. To show these elements items Marks, Curves, Isoline and Sections should be checked in the View/ Decorations menu item. If Labels item checked, than captions to visible elements will be shown. When new elements will be drawn on the image for which 3D image is built, it does not affect 3D image automatically. So new elements wont be shown there. To refresh the 3D image in this case click it with the left mouse button and hold it for a second, and release.
- The surface may be rotated round vertical axis. To fulfill this press the Left Button of the Mouse and leaving it pressed move the Mouse in Left and Right directions.
- The scale in vertical direction may be changed. Press the Left Button of the Mouse and not releasing it move the Mouse up and down.
- The image may be put closer or far. It can be done if the Mouse is moved up and down while its Left Button is pressed and keyboard button Shift is also pressed.
- The surface may be rotated round horizontal axis, lying in the monitor plane. To do it move the Mouse up and down when its Left Button is pressed and the keyboard button Ctrl is also pressed.
- If the word Highlighted is selected in the View Menu, then the surface will be illuminated. It is possible to adjust the light position, and this can drastically change the impression upon the image. Movement of the Mouse with pressed its Left Button and keyboard buttons Shift and Ctrl will lead to the movement of the light source.

– It is possible not only to adjust the light source position, but also to change the optical properties of the surface. This option is described in attachment D).

3.7.2 Curves to section conversion

User can make surface section over curve. To do this you should create a desired curve using curve drawing regime (see 3.5.7), and execute the command Convert Curve to Section. Desired section will be drawn in a new window.

3.7.3 Creating hysteresis calibration file

Creation of file for hysteresis calibration can be performed in following steps:

- In "Curve" mode, put knots in the positions with known distances between them (for convenience option "Cursor/ Snap to Maximum" can be used) (pic. 3.18)

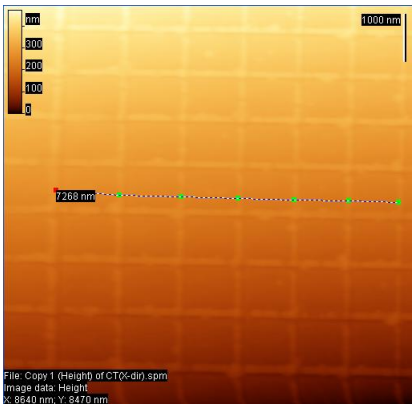


Figure 3.18. Scanned image with marked knots.

- Performing command Operations/ Create Calibration Curve, two columns can be seen in the appeared window (pic.3.19)

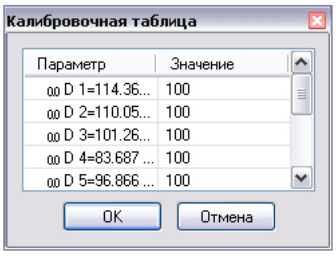


Figure 3.19. Table for definition of knot distances, required to build calibration graphs.

In the left column there are parameters (distances between knots), in the right one the real distances should be entered (for example, grating period).

- Save calibration file on the disk

- After this, program builds two calibration curves `x-calibration` and `y-calibration-slow` (for X and Y axes) and draws them on the screen (pic. 3.20):

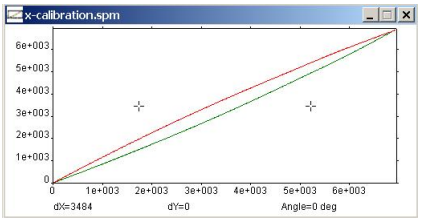


Figure 3.20. Calibration graph `x-calibration`.

On the horizontal axis, X (or Y) projection of the knots is drawn, on the vertical - true values of the same knots. Green line is built along this points, and the red one is a symmetrical graph relatively to the $X = Y$ line. This red line is used for piezo voltage correction.

There is one important moment: If knots projections on the Y (or X) axis are too small, which can happen in such case, when curve is almost parallel to the one of the projection axes (high precision along this axis) and perpendicular to another axis (low precision along this axis) – in such case two curves should be built, one for each direction (`x-calibration` and `y-calibration-slow`). (see pic. 3.21). To start building new curve, press left mouse button while holding down CTRL key – new point will start the new curve.

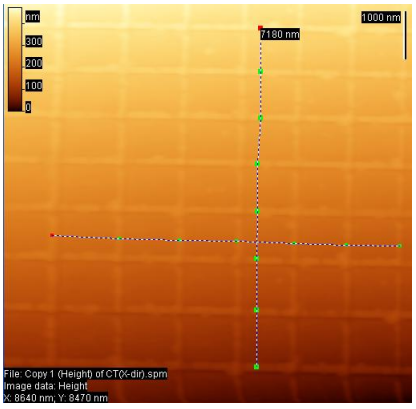


Figure 3.21. Buildig two curves on one image.

Program automatically saves data only for better direction, when projection along one axis is 3 times smaller than along another axis.

- Obtained coefficients are used in hysteresis calibration procedure during server configuration (see 2.1.2).

Obtained calibration data can be used to fix images only along one scan direction (X direction in described case). Two obtain hysteresis correction data along another scan direction, one should perform the same operations with image, obtained along Y direction. Data can be saved to another file, which can be merged with first one manually, or directly to the first file – in most cases data will be written into the proper sections `x-calibration-slow` and `y-calibration`.

3.7.4 Features searching

The objects on the surface may be searched and then enumerated using the Command Enum Features. Fig. 3.22 demonstrates what is regarded as object. The average level, mean square deflection (in fig d) and maximum value are calculated for the surface. Then two planes are compared – A and B. The plane A has the height value, which is in the middle between Average level and Maximum height. The plane B is higher than Average level by 2d (d - mean square deflection). The plane which is lower serves as a threshold and the regions of the surface higher than the threshold surface are regarded as objects.

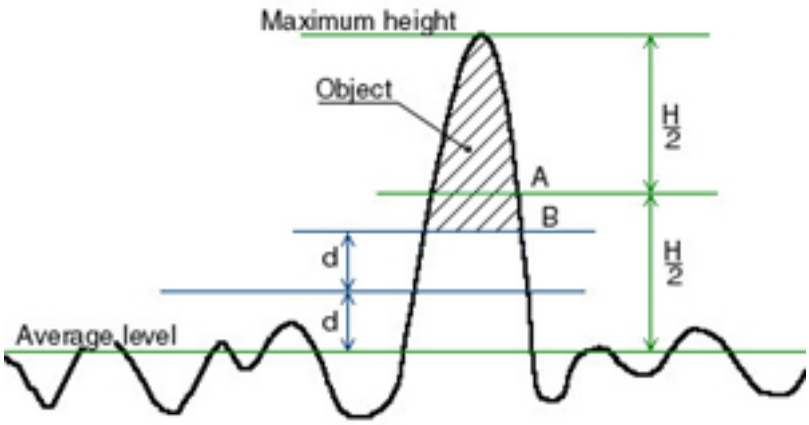


Figure 3.22. Object Search

By the Command Enum Features the marks are put on the image and two windows appears — First, the histogram window, where the size and square of the objects are shown. It is possible to move two vertical lines in this window so that to select the objects according to the square. Second, the window with table, in which different object parameters is listed. This table contends 4 columns but the column with the object number: Square, Perimeter, Volume and RMS (standard height deviation). In this table user can sort out the objects using any parameter. Objects remunerate after being sorting out. User can select the objects and copy its parameters to a clipboard. To select the objects user should click desired objects, holding CTRL or SHIFT button. To copy user should press CTRL+C or run the Copy Text command from Edit menu.

If the parameter Filter inner is selected in the Menu Features, then only the objects in between these lines will be selected. If the parameter Filter outer is selected, then only the objects outside the lines will be selected.

The selected objects may be deleted, so that their height will be adjusted to the minimal height on of the surface. This is done by the command Features/ Remove filtered from image.

Menu command Features/ Remove filtered from histogram delete non-selected objects from histogram only, and do nothing with the objects on the image.

The command Profile average height from menu Features calculates the average height of the objects. It is done in the following way. The new average level of the height of the surface is found when the selected objects are not accounted for. Then the average height of each selected objects is calculated as the average value among maximum values of the height for each line along X axis in respect to the new average level. After that the average value for the height of all the objects is estimated and shown in the right lower corner of the Window.

The parameter Show mask may be selected in the Menu Features. In this case only the selected objects will be seen. All other regions will be in black color.

3.7.5 Fourier Transform

Fourier Transform is an advanced method of surface analysis and filtering. The command Fourier serves for 2D Fourier Transform presentation of the surface image. The contrast of the Fourier image may be adjusted by Contrast in three different ways: More (contrast increase), Less (contrast decrease) and Restore (the contrast restored to initial value). All this variants may be also selected in the Falling Menu, appeared after the click of the Right Button of the Mouse in the spectrum image.

It is possible to select several arbitrary rectangular regions in the Selection Mode or put Marks in the Marks Mode. To select the mode press the Right Button of the Mouse in the spectrum image. To delete the selected region, put a mouse pointer on it - near the pointer small red cross appear - and click the left mouse button on the region.

If you have selected some regions in the spectrum image it is possible to put to zero either its inner or outer regions. The following Commands are used for it: Zero Inner and Zero Outer. These commands can be called by the Click of the Right Button of the Mouse or from the Fourier Menu. The changes in the surface image corresponding to the new Fourier spectrum will be seen immediately.

The values of periods and intensity (in arbitrary units) for the point where the cursor is placed are seen in the status line of the Main Window. When you put Marks in the Mark Mode, the corresponding period and intensity are appeared near the selected point.

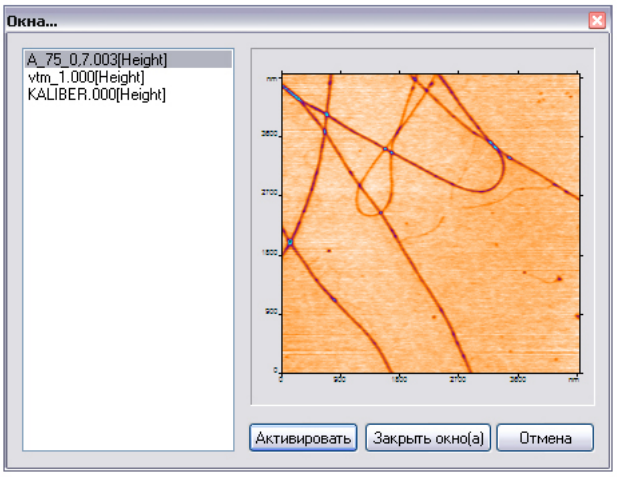
3.7.6 Histogram

The Command Histogram leads to the appearance of the Window, which present the distribution of individual points of the surface over its height. By moving vertical lines it is possible to measure the relative square of surface corresponding to the selected points. By Menu Command Histogram/ Cutoff the height of each point which is outside the vertical lines becomes equal to the height pointed by the corresponding vertical line.

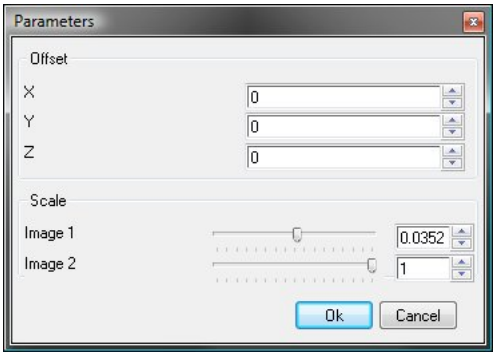
3.7.7 Addition and Subtraction of Images

Menu Command Operations/ Image Operation/ Add, Subtract and Advanced allow to add or subtract images. Using one of the command is followed by the appearance of the Window for the Selection of the Image (fig. 3.23(a)), which will be added to or subtracted from the current surface image. Press “Select” after you have selected an image. If the Commands Add or Subtract was in process, the image subtraction or addition will be performed at once. It is regarded that left lower corners of the images coincides, the new height of each point in the resultant image will be equal to half of the sum or to half of the difference of the points height of the initial images.

Additional Window appears, if The Command Advanced is selected (fig. 3.23(b)). It is possible in this case to shift the red rectangular (the first image) over the black rectangular (the second image) just in the field where they are presented. The shift may be performed in equal way by changing the parameters Xo and Yo, which are the difference in the coordinates (in pixels) of left lower corners of the images. The parameters Scale 1 and Scale 2 defines the way, how the height of the points of the resultant image will be calculated. Here is the corresponding formula $Z = (Scale1) \cdot Z_1 + (Scale2) \cdot Z_2$.



(a) Image Selection.



(b) Window for Image Addition with extended Options.

Figure 3.23. Dialogue for Images Addition and Subtraction

Please pay attention, the values along Z axis may be in different units for different images. Besides height units other units (current, voltage, friction etc) may be used. In most cases there is no sense to add such values.

3.7.8 Calculation of the Volume, restricted by the isoline

If a closed line of constant height is drawn on the surface, then it is possible to calculate the volume, which is "cut" by the line from the surface. This is done using the Command Isoline Volume.

3.7.9 Change in inner data representation

If command Resample is selected, dialog window showed on picture 3.24 appears. There are two columns of fields — Original and Destination. Fields in column Original shows current values and unaccessible for editing. In the fields in column Destination new values entered.

If you want to change values on the Z-axis, check menu items Z Scale or Z Offset. Inner data format of FemtoScan software is described here - 3.2.2. In the field Bit size user can enter a height per one bit from these two bytes, in which height data stored. The difference between Bit size field of Resample window from Bit size field of Resolution window (see 3.2.2) is in that, in the first case program change value of the two byte integer numbers (that is inner data representation) according to the field value, and in the second case the program change in accordance with the field value only coefficients, that needs to convert these integer numbers to real height data.

In a RMS field standard deviation of the surface height is indicated.

¡Z¿ field indicate the height in inner data representation, which will correspond to average surface height.

Fields Width and Height can be used to change the number of the points in the image.

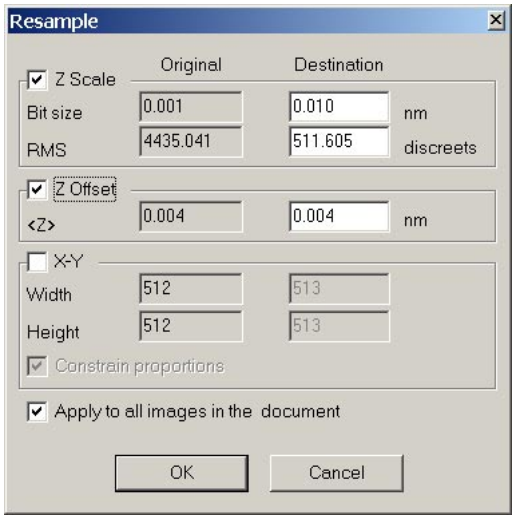


Figure 3.24. Inner data representation change window

3.7.10 Surface Corrugation

The Command Roughness calculates the mean square deflection of the height of different points on the surface from its average value ($\sqrt{\sigma^2_{Z(X,Y)}}$) in the selected area or in its whole image.

3.7.11 Calculation of the Square of the Surface Region

If you have selected a surface region on the surface, then the value of its square can be found using the Command Surface Square. It will appear S — square of the selected area and dS — the difference of this square and the square of its projection on XY plane.

3.7.12 Image Duplication

Every surface image may be always duplicated using Command Duplicate. If some region is selected on the surface, then exactly this region will be duplicated, otherwise — the whole image.

3.7.13 Highlight

Surface illumination is performed using the Command Highlight in different ways: By Angle, By Sin and By Tang. As a fact, during this operation the new color of the point is now defined not by its height, but the angle of surface inclination (by Angle), sinus of this angle (by Sin), or by tangents of this angle (by Tang). Such operations are called as gradient transformations. The button  corresponds to the option by Angle.

3.7.14 Redoubling an image

Command Redouble Redouble (button ) increase number of points in the image and put a newly generated image or selected image part in separate window. Number of points on X and Y directions increase in two times. New points calculated using linear spline method.

3.8 Dealing with Force curves

3.8.1 Force curve analysis

Program Femtoscan have set of functions for working with force curves and for curves analysis with WLC model. There are opportunities for working with single curve as well as with array of curves.

Force curve analysis module contains 3 main functions:

- Normalize force curve - for curves normalization and reducing them to a common form
- Separation Curve - for building separation curve (Force vs. Distance between cantilever and surface)
- WLC Analysis - curve analysis and values calculating as WLC model approximation

Normalize force curve

Curve must have common form for further analysis: contact region must be situated at the left part, zero level regions must be horizontal and go exactly through zero point. Contact regions of trace and retrace curves must be also combined with each other (if an array of curves is opened, all contact regions should be combined too for convenient work). All these operations can be done by using function *Normalize force curve* (button).

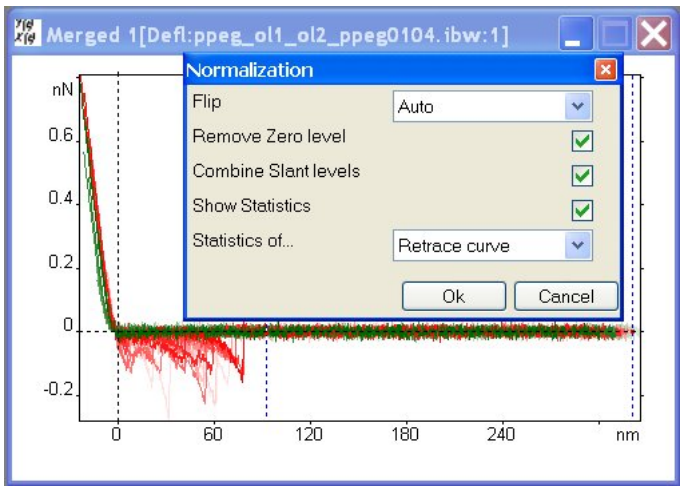


Figure 3.25. Force curve normalization.

Selection of curves for flipping can be carried out automatically (value *Auto* for parameter *Flip*) or it can be chosen by user to flip all curves (value *All*) or not to flip any (value *None*). To remove slope from curves choose interval which slope wanted to be removed using marks and set in parameter *Remove zero level*. To combine contact regions set in parameter *Combine slant level*.

If it's necessary to evaluate curve parameters (slope of contact region, linear equation for zero level, mean-square deflection), set in parameter *Show Statistics*. It can be optionally chosen to evaluate statistics of selected area (value *Selected area* for parameter *Statistics of...*) or to evaluate statistics of all trace (value *Trace curve*) or retrace curves (value *Retrace curve*). In first case selected areas for all opened images will be approximate by LMS. In second case zero and contact regions will be found and then their statistics will be evaluated.

Separation curve

For plotting of separation curve use function *Curve/Separation Curve* (button).

Two methods can be used for calculation of contact region coefficients: LMS approximation (value *LMS fit* for parameter *Method for separation curve*) or from microscope calibration data (value *Calibration*). The first method should be used only in case if there is no information about calibration (if "nm" units are not available for force axis). LMS calculation use noise level as a parameter.

WLC analysis

Analysis includes 2 stages - local minimums searching and evaluating of WLC model parameters. To conduct an analysis choose function *WLC analysis* from menu *Curve* (button). After calling the parameter window will exist (see fig. 3.27). At first select curves for analysis. If parameter

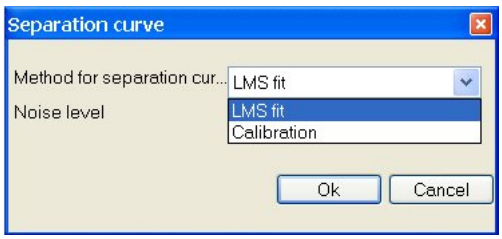


Figure 3.26. Separation curve plot.

Choose subimage isn't set in, all odd subimages will be selected for further work (it's meant that odd curves correspond to retrace). If it's necessary to use even subimages or only active one, set in parameter *Choose subimage* and select corresponding value for parameter *Number*.

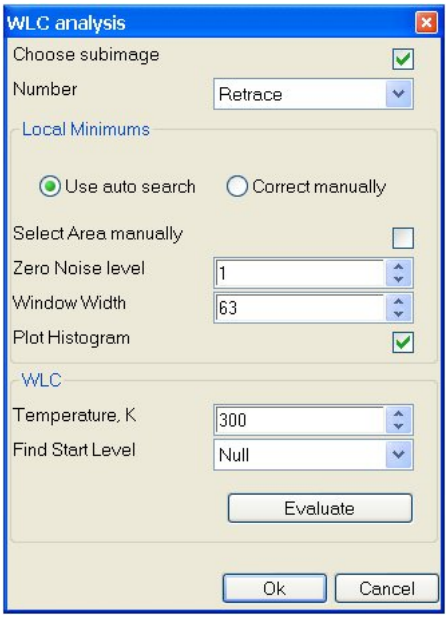


Figure 3.27. Function parameters.

There are 2 local minimums search methods: automatical search (choose *Use auto search*) and manual correct (choose *Correct manually*). It's recommended to use autosearch at first and then correct results manually if it's needed.

1. Autosearch mode.

   Area for local minimums search can be carried out automatically (parameter *Select Area manually* isn't set in) with use of noise level (parameter *Noise level*) or it can be selected manually (parameter *Select Area manually* is set in). For manual selection choose area by marks and push the button *Set*. Value selected for parameter Window Width corresponds to size of local minimum environment. Found local minimums are plotted at the image as blue points, local maximums are also plotted as green points. WLC approximation will be realized for each part of curve from local maximum to the next local minimum.

2. Manual correction.

To correct found intervals add new one in manual correction mode select right interval by marks and push the button *Correct by marks*.

Statistical analysis of local minimums is available. To use it set in parameter *Plot histogram*. After that local minimums histogram will be plotted and all local minimums will be outputted in the form of table (see fig. 3.28).

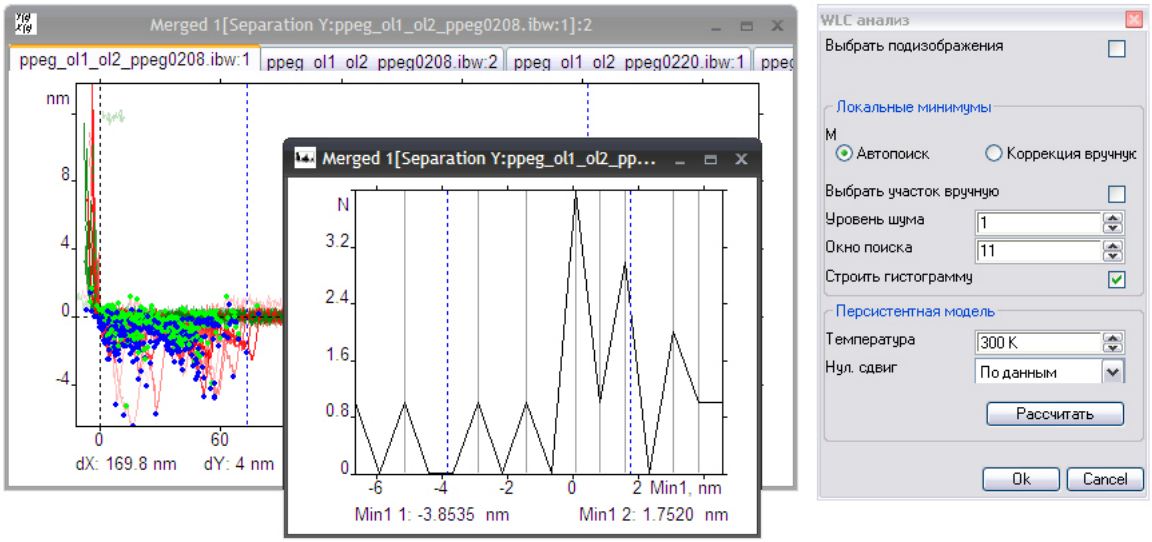


Figure 3.28. Local minimums search.

Each new row in table corresponds to new subimage, column - to the number of minimum from the begining of each curve. Histogram is plotted for selected column. If one row is selected, then corresponding subimage became active.

Region of the histogram can be selected by marks. After that table will contains only that curves which minimums from active column are inside selected region. There is a set of functions in menu *Items* for working with histograms. Use function *Remove not used* to remove trace-retrace subimages without local minimums. Use function *Remove filtered* to remove curves, that were filtered by histogram. Use function *Remove selected* to remove curves, that were selected by histogram. To delete active curve with corresponding trace or retrace one use function *Curve/Remove active curve*.

If all local minimums was found correctly, WLC analysis can be carried out. At each part of curve from local maximum to the next local minimum force curve can be approximated with WLC model. Values for temperature and calculation algorithm must be set in parameter window. There are 3 algorithms: *Null* - with null vertical shift, *From data* - with additional vertical shift parameter for each interval, *Superposition* - with taking superposition into account, i.e. analysis starts from the rightmost interval, left ends of curves for intervals that were already processed are subtracted from each further interval data. To start processing push the button *Calculate*. Results will be outputted as a table (see fig. 3.29).

Following values are outputted: Subimage - subimage number, Curve - number of found approximation curve at this subimage, Fmin - rupture force, Xmin - rupture length, Lp - persistent length, Lc - contour length, F0 - vertical shift F0, which was used as additional parameter during approximation, Extension - relative extension, dF/dx - derivative for curve in rupture point.

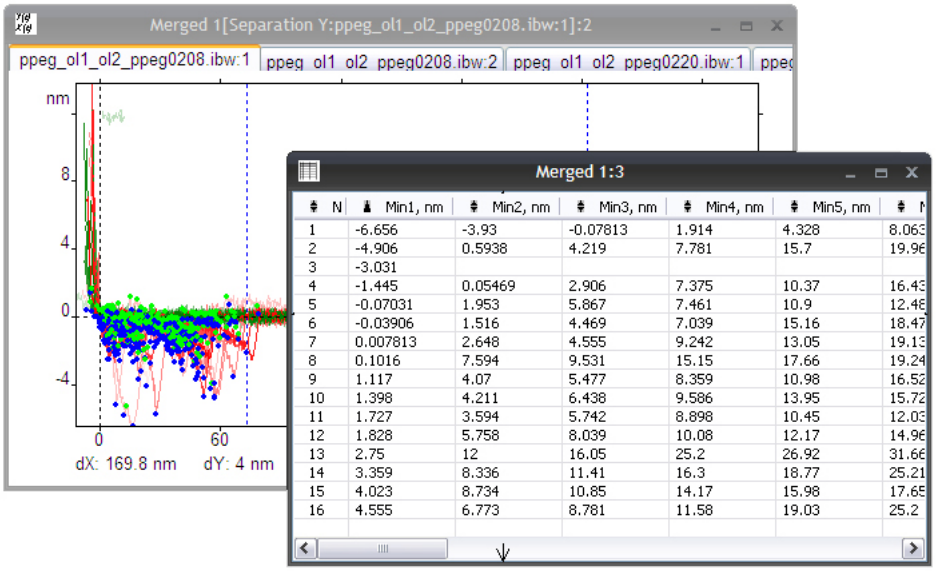


Figure 3.29. Results output.

3.9 Dealing with Clipboard

There are three commands which deal with the Clipboard: Copy, Copy Text and Add Text. The command Copy put a copy of the Active Window into the Clipboard. The command Copy Text copies text information into the Clipboard, the previous information in the Clipboard will be deleted. Command Add Text adds text data into the Clipboard, but does not delete the previous one.

3.10 Undo and Redo

When you are working with an image, the program records changes that were done, so you can undo every change you've made by menu command Edit/ Undo (button). You can restore the changes that were undone by menu command Edit/ Redo (button). Note: Program does not store changes in data representation like palette color, marks that were put, sections, etc... So these operations cannot be restored by using undo/redo commands.

3.11 Dealing with Windows

3.11.1 Ordering Windows

Ordering Windows can be done by two Commands Cascade and Tile from the Menu Window. The Command Cascade will put the Windows one after another in diagonal direction starting from the upper left corner of the Window. The Command Tile put the Windows without intersection one by one from left to right and from up to down.

If the active zone contains the minimized Windows, then after the Menu Command Windows/ Arrange Icons the headings of this windows will be closed in compact form from left to right and from up to down starting from the left lower corner.

If you want to open all the Windows (both seen and minimized) select the Command Close All of the same Menu.

3.11.2 Window scrolling

Using mouse with scrolling wheel it is possible to scroll content of main program window. To scroll vertically, just move scrolling wheel, to scroll horizontally — moving wheel holding CTRL button.

3.11.3 Image Selection

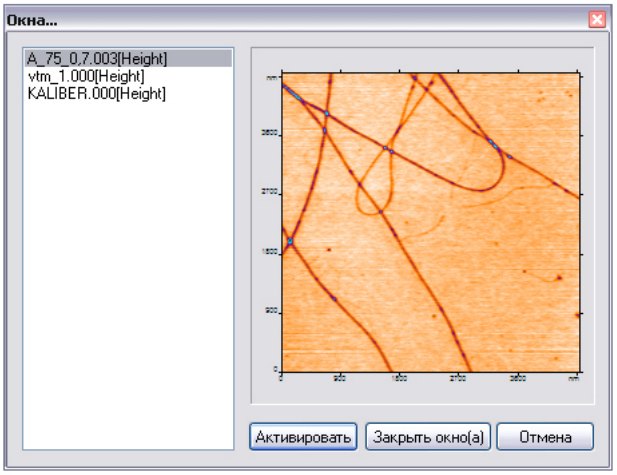


Figure 3.30. Window of Image Selection

The necessary image may be easily found using the Command Windows/ Windows.... The dialogue Window appears with a list of all opened Windows (fig. 3.30). Moving along the list you will see in the right side of the Dialogue Window a small image of the selected Window. The Window will become active after pressing the button “Activate”. By pressing “Close Window” the selected Window will be closed.

It is possible to select the necessary image in a more easier way. The list of opened Windows is shown in the lower part of the Window, but not more than 9 images are shown there.

3.11.4 Changing window size

User can change an image window size using standard Windows routine. To change the window size, point the Mouse to the window border. The mouse pointer changes into a double-headed arrow, and then you can drag the border holding left mouse button. During window size changing two dashed lines will be shown with the captions, that shows window size in pixels.

3.11.5 Restoring the Window’s size

If you have extended or compressed the Window using standard Windows operations, then it is possible to restore its original size using the Menu Command View/ Normalize.

3.11.6 Format of Legend

The legend is usually seen in the image. It consists of scale bar and additional information about the file and image parameters. If the additional information is not needed, then remove the tick in the Menu against Show File Info. If the whole legend is not needed — remove the mark against View/ Show/ Legend.

Appendix A

Software Installation

To install the software launch the program setup.exe, which is present at the installation disk. You will have to write a serial number during the program installation. Serial number is received from the Advanced Technologies Center during the software purchase. The rest of operations will be done in automatic regimes.

In case you install server part of the software (if you choose Server software, Full or Custom options during software installation), you need: 1. Operating system of the Windows 2000, Windows XP or Windows 2003 Server family installed on your computer. 2. You should log on to your computer as administrator or as a user with administrator rights.

Otherwise installation program alerts you that installation couldn't be completed, and you will be prompted to choose if you want to install the software with different components or to cancel the installation.

You should restart your computer after installation is finished in order to start DSP board driver.

Appendix B

Description of file data format for temperature calibration of temperature controlled sample table

File is written in text format and consists from one section. The section begins with header

`[data]`

and continues until end of file. The section contains a number of records. A record has following format:

`<voltage>=<temperature>;`

`<voltage>` and `<temperature>` - numbers in ordinary scientific format - with the period (.) as a decimal divider.

Example of temperature initialization file listed below.

```
[temperature]
-3.00=27.5;
-2.67=28.0;
-2.33=29.0;
-2.00=31.5;
-1.67=33.5;
-1.33=36.0;
-1.00=37.0;
-0.67=39.0;
-0.33=42.0;
0.00=42.5;
0.33=45.0;
0.67=47.5;
1.00=49.0;
1.33=50.0;
3.00=60.0;
```

Appendix C

COM-port initialization file format

This file is written in text format and consists from several sections. The order of this sections doesn't important. Every section starts with header like this —

```
[<section_name>]
```

and lasts until next section starts or until the end of file. Every section content several records. The record has this format —

```
<record_name>=<value>;
```

These sections should be described in the file: `init`, `sample`, `var`, `var.scale` (not nessesarly) , `var.display` (not nessesarly).

Variables are described in `var` section. Variable names can de substituted in the record values with $ sign. In the case when section `var.scale` is exist, in this section scale coefficients for conversion of variables values to numbers can be set. Then values, multiplied to these scale coefficients, will appear in a Parametres window of the client's software.

If the `var.display` section is exist, the alternate, more convenient variables names, can be set in the section. The section `init` have to contain following records:

- `RdInterval` - maximum interval (in milliseconds) between two consecutive symbols that was read from a port.
- `RdTotMult` - maximum time of reading for one symbol.
- `RdTotConst` - reading constant; Program cancel reading for a string containing N symbols from a port due to time-out if reading time exceeds N*`RdTotMult`+`RdTotConst`, or interval between reading of two consecutive symbols exceeds `RdInterval`.
- `WrTotMult` - maximum time of writing for one symbol.
- `WrTotConst` - writing constant.
- `Speed` - equation, that set maximum data reading speed (in Hz). Variables, numbers, operations `+ - * /` and brackets `( )` can be used in this equation. Multiplication and division operations has a higher priority than addition and subtraction.
- `init` - Device initialization string; the string consist of numeric values, delays and escape-functions, divided by commas. Numeric values can be decimal (like `123`), Hex (`0xa1`) or Oct (0175) format. Every numeric value corresponds to one byte of information to be send. Delay

should be written as `!<time in milliseconds>`, for example `!500`. Escape-function is one of following values:

  - `CLRDTR`
  - `CLRRTS`
  - `SETDTR`
  - `SETRTS`
  - `SETXOFF`
  - `SETXON`
  - `SETBREAK`
  - `CLRBREAK`

- `init_read` - Number of bytes needed to be read after string `init` have been sent.

Section `sample` should contain following records:

- `init` - single string, contain loading initialization values. String must consist only from numeric values, divided by commas.
- `init_read` - number of bytes, that needed to be read after the string `init` is sent.
- `lobyte` - value's low byte loading initialization string.
- `lobyte_read` - number of bytes, that needed to be read after the string `lobyte` is sent.
- `lobyte_offset` - value of string's low byte offset, can be negative.
- `hibyte` - value's high byte loading initialization string.
- `hibyte_read` - number of bytes, that needed to be read after the string `hibyte` is sent.
- `hibyte_offset` - value of loaded string's high byte offset, can be negative.

Communication with a port goes according to following scenario:

- If additional data channel is enabled (2.1.2) during DSP board initialization it sends strings `[init]init` to chosen COM-port and reads `[init]init_read` bytes.
- During image acquiring in every acquired point program sending string `[sample]init` to a port and reading `[sample]init_read` bytes from it. After reading is done, it send `[sample]lobyte` string and read `[sample]lobyte_read` bytes. From the loaded data, length of which is `[sample]init_read` + `[sample]lobyte_read`+`[sample]hibyte_read`, it take two bytes with offsets `[sample]init_read` + `[sample]lobyte_offset` and `[sample]init_read` + `[sample]lobyte_re` + `[sample]hibyte_offset`, and from these bytes it form 16-bit result.

An example of initialization file listed below.

```
[init]
RdInterval=500;
RdTotConst=500;
RdTotMult=500;
Speed=1.0/(2.0e-6*$CCPR2*$TMRQuanta);
```

```
WrTotConst=0;
WrTotMult=0;
init=SETRTS,!100,CLRRTS,!100,0x74,$Uhv,0xf4,0x74,$Ud,0xfc;
init_read=6;

[sample]
hibyte=0xa6;
hibyte_offset=0;
hibyte_read=1;
init=0x30,$C_DvdReg,0x1c,$CCPR2High,0x1b,$CCPR2Low,0x29,$TMRQuanta,0xf2;
init_read=9;
lobyte=0x81;
lobyte_offset=0;
lobyte_read=1;

[var]
CCPR2(Cntr),int,0,0xffff=256;
CCPR2High,int,0,255,,#CCPR2 >> 8=#CCPR2 >> 8;
CCPR2Low,int,0,255,,#CCPR2 & 0xff=#CCPR2 & 0xff;
C_DvdReg(Div),int,0,255=0;
TMRQuanta(Cntr T, ms),int,0,255,0.05*##=40;
Ud(Ud, V),int,0,255=20;
Uhv(Uhv, V),int,0,255=200;
sample_freq,double,,,,,1.0/(2.0e-6*#CCPR2*#TMRQuanta)=1;
```

Appendix D

Parameters of 3D Images

The functions of OpenGL Library used during 3D image reconstruction. The parameters of 3D images use the parameters (fig. D.1) included in the lighting equation of this Library of the following type:

$$L = I_E^M + R_A^M \cdot I_A^S + \sum_{i=1}^{n} (R_A^M \cdot I_A^{L_i} + R_D^M \cdot I_D^{L_i} \cdot (\overline{N} \cdot \overline{N}_{L_i}) + R_S^M \cdot I_S^{L_i} \cdot (\overline{N}_V \cdot \overline{N}_{L_i})^{Sh^M})$$

where

- I_E^M - Intensity of material emission (Mat. Emission).
- R_A^M - material color for diffused light (Mat. Color).
- R_D^M - material reflection color for directed light (Mat. Color).
- R_S^M - material reflection color for reflected light (Mat. Specular)
- I_A^S - scene ambient intensity (Scene Ambient)
- n - number of light sources (in our case - 1, if the illumination is switched on, and 0, if switched off) is selected using Menu Command View/ Hilighted)
- $I_A^{L_i}$ - intensity of diffused light (Light Ambient)

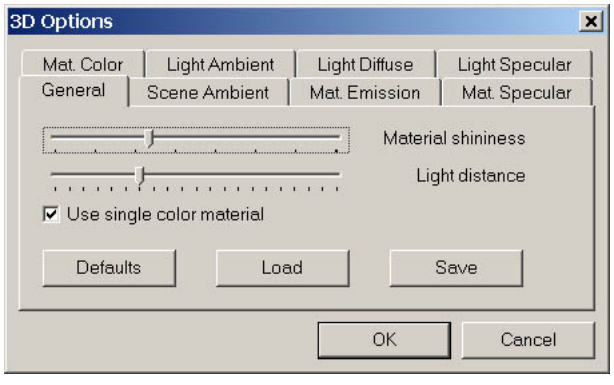


Figure D.1. Parameters of 3D Images

- $I_D^{L_i}$ - intensity of directed light (Light Diffuse)
- $I_S^{L_i}$ - intensity of reflected light (Light Specular)
- $\overline{N}$ - vector normal to the surface
- $\overline{N}_{L_i}$ - vector directed from the surface point to the light source
- $\overline{N}_V$ - vector directed from the surface point to the observer
- Sh^M - Material Shininess)

In our case we use the model, where $R_A^M = R_D^M$, and this parameter is called Material Color. If the mark Use single color material is selected in tab General then the color will be taken from option Material Color, otherwise - from the current palette according to the height of the point.

R, G and B component of each parameter may be defined using the scroll bars or a color selection dialogue. This dialogue appears by pressing Left Button of the Mouse in the color rectangular, place din the right part of the corresponding tab.

The current parameters may be stored into the file with extension .3dopt. The parameters may be read from the file or default parameters can be selected.

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